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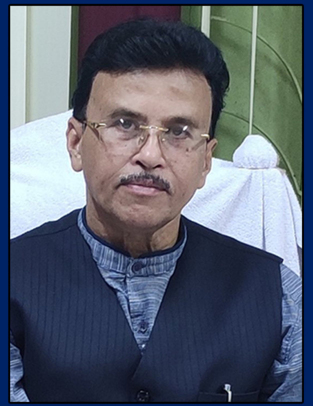

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Life as Basic Science: an Overview and Prospects for the Future

Dr. Somnath Das, Dr. Ashis Kumar Panigrahi, Dr. Rose Mary Stiffin, Dr. Jayanta Kumar Das

Life as Basic Science:

an overview and prospects for the future

VOL. 1

Dr. Somnath Das
Dr. Ashis Kumar Panigrahi
Dr. Rose Mary Stiffin
Dr. Jayanta Kumar Das

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This book is focused on the different fields of scientific research that incorporate multi-disciplines namely, aquaculture, fish biology, fisheries, microbiology, education, artificial Intelligence, physiology, cancer biology, and human health and their relationship, as well as implicate laboratory research experiments on life as science. It is aimed to help researchers, educationists, aquaculturists, and other professionals to explore extensively in mentioned fields of research encompassing life science. Therefore, in this book, authors of different chapters wrote and explored with scientific evidence, but life in different fields that emphasize multidisciplinary biological processes. This book includes eighteen different chapters written by multi-divergent fields of researchers who brought their benchside and laboratory research to you.

Finally, in an assumption of this type, it is inevitable that undetected errors creep in and remain despite the best efforts of authors and editors. Readers are persuaded to report any mishaps which will be taken seriously into consideration for future updates. We hope that this book assists each reader to understand and apply the basic principles of life to their situation.

Dr. Somnath Das
Dr. Ashis Kumar Panigrahi
Dr. Rose Mary Stiffin
Dr. Jayanta Kumar Das

Contents

~The End~

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Chapter- 1

Exploring the Potent Anticancer Activity of *Andrographis paniculata* (Kalmegh): Mechanisms, Applications and Therapeutic Implications

Avijit Chakraborty[#], Shamim Hossain Mandal[#], Soumik Debnath and Jaya Bandyopadhyay*

Keywords: Anticancer, Andrographolide, cancer, drug, medicinal plant, bioactive compound

Abstract:

Despite advancements in therapeutic approaches, cancer appears to be biggest cause of death globally. Consequently, the primary focus should be on early cancer detection, developing the best possible treatment plan to extend the patient's life, and continuing the hunt for more potent and targeted drugs to treat various cancer types. Stronger anti-cancer drugs have been developed as a result of the current change in natural chemical research towards sophisticated and molecular-level understandings. Infertility, ovarian failure, liver, renal, and heart toxicity, as well as immunosuppressive side effects, are some of the adverse consequences of synthetic medications used in cancer treatment. Consequently, herbal medications may be utilised as an adjuvant therapy in the treatment of cancer. Different plant derived drugs are under research. Among the different medicinal plants, *Andrographis paniculata* (Burm. F) Nees, an herbaceous plant of the Acanthaceae family, is often referred to as the “king of bitters,” plays an important role in the treatment of cancer. This plant is commonly used in India, China, Malaysia, and Thailand to treat sore throat, flu, and upper respiratory tract infections. This plant is rich in bioactive compounds. Andrographolide is widely regarded as a vital bioactive component of *A. paniculata*. Andrographolide has a highly bitter taste, is colourless, and is crystalline in appearance. Analgesic, antipyretic, anti-viral, antimalarial, anti-hyperglycemic, hepatoprotective, immunological modulatory, protective against alcohol-induced toxicity, cardiac protective action, and anti-cancer activity are just a few of the many potentials for andrographolide. It is reported that when andrographolide is treated on different cancer cells it possesses anticancer activity.

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Introduction:

Globally, cancer ranks as the second most common cause of death (Das et al., 2022; Kulkarni et al., 2023; Madhu et al., 2023). According to WHO cancer affects one in five individuals globally at a certain point in their lives. Even with the advancements in cancer therapies, such as traditional chemotherapy, surgery, radiation therapy, immunotherapy and hormone therapy, the overall disease-free survival percentage remains low. More difficulties arise from the toxicity that is frequently connected to anti-cancer medication therapy (Chakrovorty et al., 2021; Madhu et al., 2022; Kesavan et al., 2023; Mehta et al., 2023). As a consequence, there is growing enthusiasm for the production of safe, alternative medications, such as using organic compounds obtained from plants to cure and prevent cancer. Because of their accessibility and large safety margin, chemicals extracted from plants have significantly aided in the creation of new drugs and are now being explored to fight against cancer (Tundis et al., 2023). An enormous amount of study on various plant species and their medicinal principles is currently being done to revalue traditional medicine around the world. Reactive oxygen species (ROS) and free radicals (FR) have been linked to a wide range of illnesses, according to experimental data. Plants can be a source of novel molecules with antioxidant activity since they generate a large amount of antioxidants to counteract the oxidative damage brought on by sunlight and oxygen. The world's ancient therapeutic framework, Ayurveda (ayus = life, veda = knowledge, meaning science of life), is being fully restored under the moniker Maharishi Ayurved (Scartezzini and Speroni, 2000). Plants are a natural substance that has been used to cure a variety of illnesses, including cancer (Rami et al., 2023). It is astounding how many and how different kinds of plants there are in the world that have therapeutic qualities. An estimated 70,000 plant species—from lichens to enormous trees—have been utilised medicinally at some point in history (Kuruppu et al. 2019). *Andrographis paniculata* (Burm.f.) Nees are a common plant in tropical regions like Asia that belong to the Acanthaceae family. One of the most significant therapeutic plants in the Ayurvedic and Unani framework —the two oldest known medical systems—is *A. paniculata*. This herb has been utilised in herbal remedies to treat a range of degenerative and infectious disorders (Saxena et al. 2010). It is well recognised that diterpene lactone molecules and *A. paniculata* biological activity are related. The most stable cyclic ester of organic acid is the lactone group, which has five members (gamma lactone). Numerous biological functions, including antibacterial, antifungal, and anticancer properties, have been reported (Suriyo et al., 2021). Andrographolide and its derivatives include neoandrographolide, andrograpanin and 14-deoxy-11,12-didehydro andrographolide. Due to its many medical qualities, andrographolide has been extensively researched. Some of these features include its anti-cancer, antibacterial, antioxidant, anti-inflammatory, antidiabetic, and antiviral effects. In meanwhile, 14-deoxy-11,12-didehydroandrographolide has demonstrated antiviral, antifungal, and anticancer properties (Adiguna et al., 2023). In breast cancer cells, 14-Deoxy-11,12-didehydroandrographolide shows a strong hold on the cell cycle process and cell cycle arrest. Moreover, it induced autophagy in carcinoma cells (Tan et al. 2012). Furthermore, neoandrographolide has been demonstrated to demonstrate anti-inflammatory, anti-viral and hepatoprotective activities (Zhang et al., 2020).

Botanical and Taxonomic description of Andrographis paniculata:

An annual herbaceous plant, *A. paniculata* is branched, upright, and grows in hedgerows in level areas, hillsides, waste grounds, farms, wet habitats, seashores, and roadsides. It may be grown in gardens as well. For their proper development, wastelands, woods, and moist, shaded areas are preferred. The physiological and morphological information of *A. paniculata* are discussed in Table 1**.** This plant is grown in many places throughout Southeastern and Southern Asia, such as India, Sri Lanka, Indonesia, Java and Pakistan. It is also grown in the West Indies, including Jamaica, Hong Kong and Bahamas Barbados; tropical regions of America; and southwest Nigeria (Hossain et al., 2014). *A. paniculata* is widely used because, in contrast to other species in the genus, it is commonly found throughout much of India, which includes the hilly and plain regions up to 500 m (1,600 ft). The taxonomic description of *A. paniculata* is furnished in Table 2.

Table 1: Botanical description of *A. paniculata* (Dandekar et al., 2024).

Traits	Characteristics/ Values
Plant height	31-102 cm
Stem	Green (Dark)
Length	31-102cm
Diameter	2-6mm
Shape	Oblong, with wings on the younger, angled portions and longitudinal furrows; the nodes are slightly larger.
Leaves	Glabrous
Length	8.0 cm
Width	2.5cm
Arrangement	Pinnate, lanceolate
Flowers	White petals with rose-purple marks
Size	Tiny, loosely spreading terminal and auxiliary racemes or panicles
Seed capsules	Oblong-linear, sharp at both ends
Size	1.90 cm × 0.31 cm

Shape	Sub quadrate, numerous

Table 2: Taxonomic description of *A. paniculata* (Dandekar et al., 2024)

Classification	Common name and Scientific name
Kingdom	Plants, Planate
Subkingdom	Vascular plants, Tracheobionta
Super division	Seed plants, Spermatophyta
Division	Angiosperma
Class	Dicotyledonae
Subclass	Gamopetalae
Series	Bicarpellatae
Order	Personales
Tribe	Justicieae
Family	Acanthaceae
Genus	Andrographis
Species	*A. paniculata* (Burm.f) Nees

Bioactive compounds:

More than 20 diterpenoids and more than 10 flavonoids have been identified as active chemicals from *A. paniculata* that have been extracted using methanol or ethanol from the leaf, stem, and whole plant. Approximately 0.8~1.2%, 0.5~6% and 4% of the stem, leaf, and dried whole plant extracts, respectively, contain andrographolide ($C_{20}H_{30}O_5$), the primary diterpenoid in *A. paniculata* (Chao and Lin, 2010). The remaining primary diterpenoids are isoandrographolide, 14-deoxy-11,12-didehydroandrographolide, deoxyandrographolide and neoandrographolide. The primary flavonoids that were isolated from the methanol or ethanol extract's ethyl acetate (EtOAC)-soluble fraction were 2'-methyl ether, 5-hydroxy-7,8-dimethoxyflavone, 5-hydroxy-7,8,2', 3'-tetramethoxyflavone, 5-hydroxy-7,8,2'-trimethoxyflavone,7-O-methylwogonin and 5-hydroxy-7,8,2',5'-tetramethoxyflavone (Sarma, 2016; Chao et al., 2010). The other component consists of macro and trace elements, xanthones and polyphenols (Chauhan et al., 2019).

Andrographolide and Its Derivatives-Pharmacological Importance:

In the present era, various pharmacological aspects have been documented for andrographolide and its derivatives, e.g., anti-cancer, anti-hyperglycemic, hepatoprotective, anti-inflammatory, neuroprotective, anti-viral, anti-fibrosis, anti-atherosclerosis, antioxidant, cardiovascular protective and antimicrobial actions. Andrographolide can scavenge free-radical as well as it can stop inflammation by blocking nitric oxide (NO) induced by lipopolysaccharide synthesis and inducible NO synthase (iNOS) expression, as well as by decreasing IL-2 production and proliferation of T-cell. Depression, neuro-inflammation, Parkinsonism, Alzheimer's disease, and deficiencies in spatial memory can be treated by lactone diterpene (Zhang et al., 2021). Research has revealed that the active components in *A. paniculata* extract have antiviral properties, including defence against ribonucleic acid and DNA viruses. Andrographolide has been demonstrated in silico experiments to inhibit the primary protease of SARS-CoV-2. The HIV, influenza A and HSV-1 viruses may all be effectively inhibited by 14-deoxy-11,12-dehydroandrographolide. However, because of its limited solubility, bitter taste, low stability in the gastrointestinal tract, and low bioavailability, andrographolide and its analogues are currently being studied for their potential benefits. Therefore, while developing therapies, it is important to give careful thought to the dose form of andrographolide and the compounds developed from it (Adiguna et al., 2021).

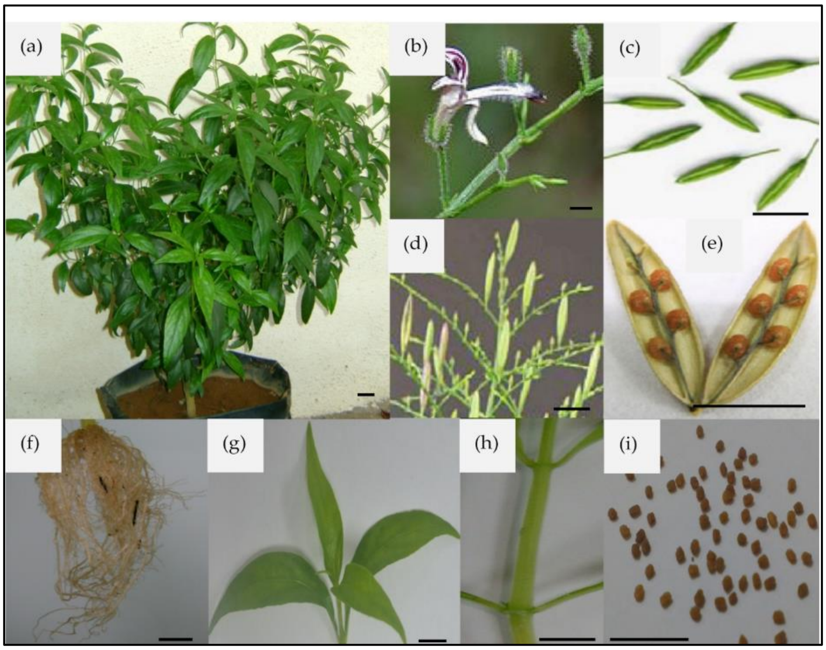

Figure 1. The distinct portions of *Andrographis paniculata*: (a) Aerial segment, (b) flower, (c) panicles on the pod stage: an adult capsule, (d) fruit, (e) capsule after opening, (f) roots, (g) leaves: opposite arrangement, (h) stem, and (i) seed (Hossain et al.)

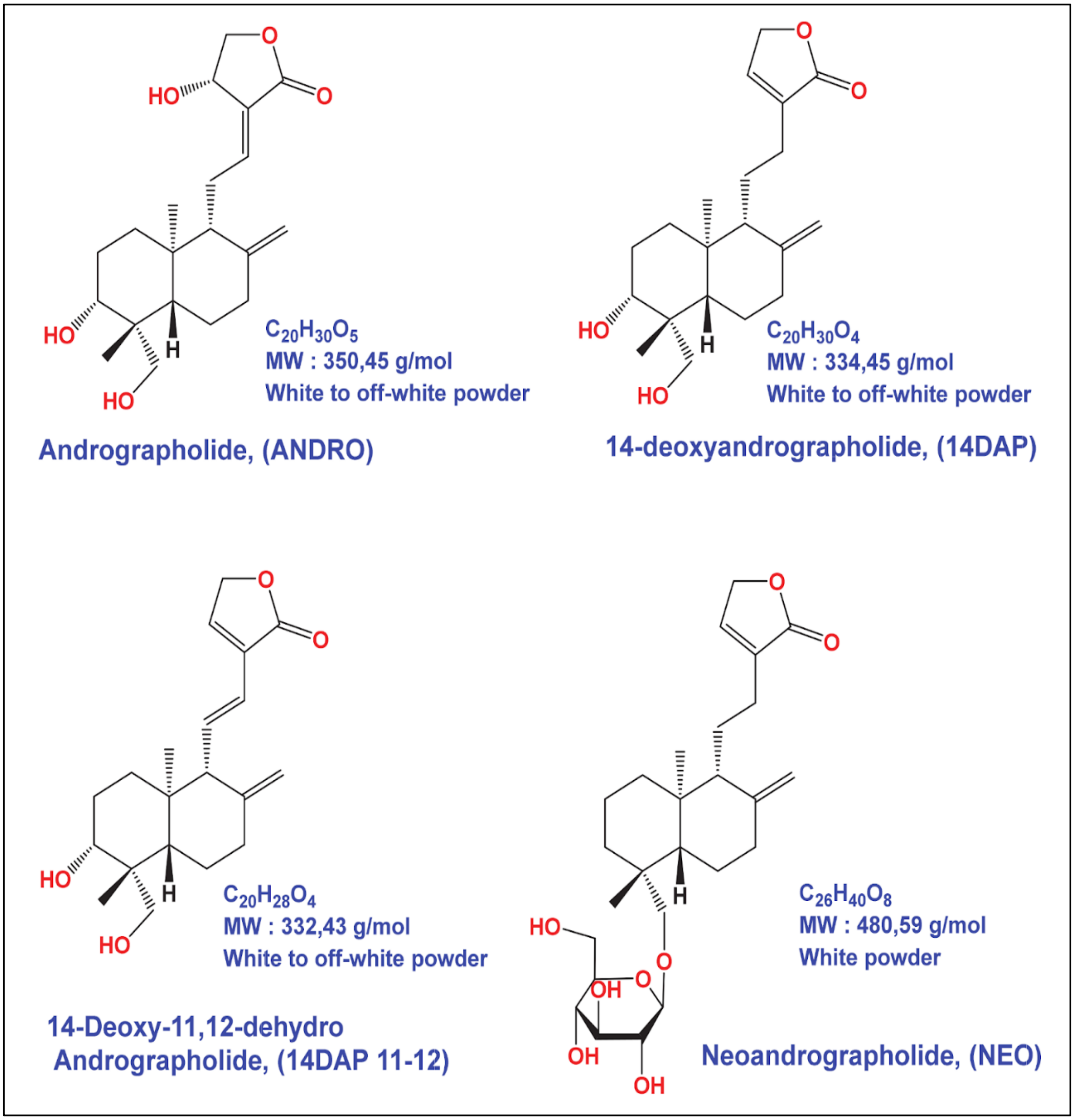

Figure 2. Chemical structure of andrographolide and its derivatives (Mussard et al., 2020)

Pathways involved in cancer:

Early tumours lack apoptosis, allowing proliferating cells to divide and spread. Excessive cell division leads to cancerous tissue growth and metastasis. Proteins and matrix metalloproteases regulate cell-cell adhesion and metastasis progression (Chaudhry et al., 2022). The identification of genes that suppresses tumour (e.g., BRCA1, TP53 and PTEN) and oncogenes (e.g. BRAF, KIT, MYC and RAS) has led to an enormous amount of information on genetic abnormalities linked to cancer (Campbell et al., 2020; Boga & Bisgin, 2022; Kaur, 2023; Mishra et al., 2023). Signalling pathways and molecular networks are crucial in the regulation of pro-growth and pro-survival cellular activities, primarily responsible for cancer development and potential treatments (Yip and Papa, 2021). In cancer, the pathways that transduce signals (e.g., Ras/MAPK and PI3K/AKT/mTOR) are often altered or activated. These linked cascades provide upstream signals to intracellular effector proteins and regulators of the cell cycle from receptor tyrosine kinases (RTKs) (Pons-Tostivint et al., 2017). The MAPK and PI3K pathways are closely linked through loop of negative and positive feedback. For example, rapalogs can induce MAPK reactivation, leading to resistance to mTORC1 inhibition. Combining mTOR and MAPK targeting improves therapy sensitivity, as demonstrated by rapalog-induced MAPK reactivation (Janků et al., 2014; Yip and Papa, 2021). According to recent research, pyruvate and lactic acid are strong inducers of intestinal CX3CR1+ phagocytes' GPR31-mediated dendritic processes, which may strengthen the immune response. These results imply that GPR31 may be a good target for antitumor treatment and may have a complicated role in the initiation and spread of cancer (You et al., 2023). GRP91, also known as succinate receptor 1 (SUCNR1), is extensively expressed in a variety of organs. SUCNR1 is a citric acid cycle intermediate molecule that is activated by succinate. Research has demonstrated that SUNCR1 is crucial for tumour metastasis, particularly in those with germline mutations in succinate dehydrogenase (SDH). By combining SUCNR1 in tumour cells and upregulating HIF-1α, extracellular succinate stimulated the PI3K-Akt pathway, boosting cancer cell invasion and causing epithelial-mesenchymal transition (Mak et al., 2010). Studies on the NF-κB signalling pathway in cancer have been going on for many years. Many solid tumours, including gastric cancer and colorectal cancer, commonly exhibit aberrant activation of NF-κB transcription factors. Members of the NF-κB pathway and its regulatory genes regulate the development, proliferation, metastasis, and drug tolerance of cancer cells through blood vessel creation (He et al., 2021). Cancer growth and spread are significantly influenced by p73 and p63, two homologs of the tumour suppressive transcription factor p53. They have excellent structural similarities, allowing most p53-responsive promoters to be bound for transcription with different but overlapping functions (Dötsch et al., 2010). TP53 gene mutations are responsible for 50% of human cancer cases. Wildtype p53 inhibits cell division to prevent cancerous growth, while TP53 mutations disrupt the cell cycle, causing cells to lose control over their own proliferation, leading to the spread of damaged DNA into progenies, resulting in malignant growth (Marei et al., 2021).

The mechanism of action and anti-cancer properties of andrographolide and its derivatives:

Recently, there has been a lot of interest in the ability of fighting against cancer and tumour by andrographolide and its derivatives. In terms of preventing the growth, spread, and migration of different cancerous cells, such as colorectal cancer cell lines, leukemic HL-60 cells, cells of breast cancer, bladder cancer, colon cancer chronic myeloid leukaemia cell lines, murine leukaemia cells, prostate cancer cells, adenocarcinoma PC-3, lymphoma, and many more other cancer cells, these chemicals have shown encouraging anti-cancer properties (Zhang et al., 2021). Recent research confirms the anti-cancer benefits of diterpene found in *A. paniculata* against various cancers, including cervical, renal, breast, lung, colon, and hepatoma cancer. However, more research is required to find out the primary mode of action (Zeng et al., 2021; Saha and Yadav, 2023). The way in which andrographolide and its derivatives work to prevent cancer are discussed below.

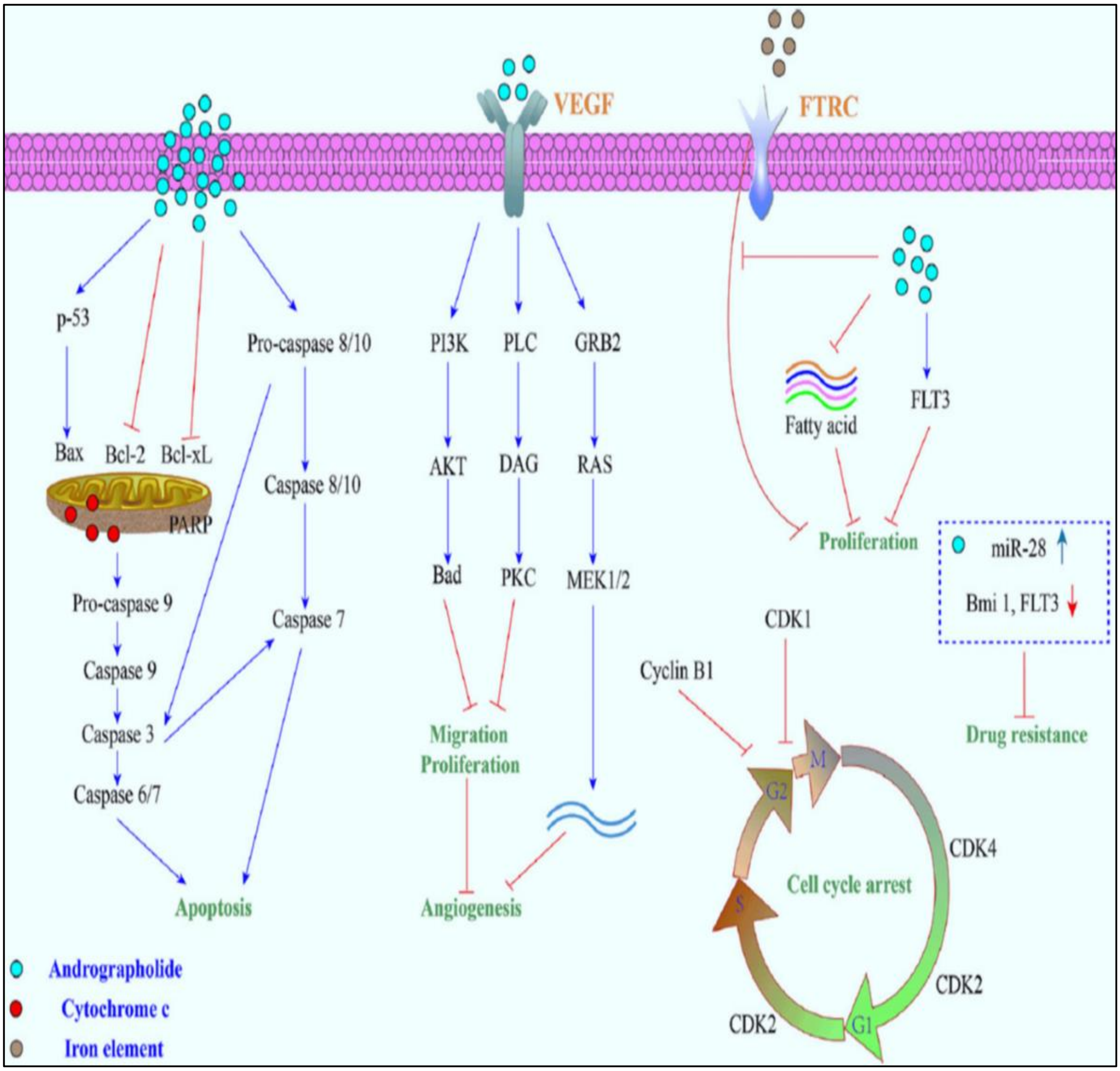

Figure 3. An illustration of andrographolide's anti-cancer mode of action (Tundis et al., 2023)

Induction of Growth Inhibitory Activity and Apoptosis:

In several human cancer cell types, andrographolide causes apoptotic cell death by activating the extrinsic death receptor pathway, which includes caspase-8 and caspase-3. Bax, Bcl-2 family member and bid, having ability of pro-apoptosis are essential in relaying the andrographolide-induced signal of cell death. Cytochrome c discharge and apoptotic cell death are the ultimate outcomes of this signal, which is initially sent to mitochondria from caspase-8 and subsequently to downstream effector caspase 3. A recent study found that in several cell lines of human carcinoma, treatment of andrographolide significantly enhanced the level of TRAIL, which stands for TNF-α-related apoptosis inducing ligand, an essential part of the extrinsic apoptosis pathway (Varma et al., 2011). Bhat and Murthy (2021) have reported that apoptotic cell death was induced in human ovarian teratocarcinoma (PA-1) cells. In comparison with the cells without treatment, there was a reported rise in the cell number having caspase 3 activation and a decreased Bcl-2 following therapy with andrographolide. Shi et al. (2008) revealed the andrographolide's pharmacophore action and how cells are halted in the G1/S stage of the cell cycle by using the CKI–cyclin–Cdk network. Also, it induced a G0/G1 stage halting in MCF-7 cells. Furthermore, in rheumatoid arthritis, andrographolide at dosages of 10–30 μM demonstrated pro-apoptotic and growth inhibitory effects through decreased levels of CDK-4 protein, a decreased Bcl2/Bax ratio, and G0/G1 stage halting in the cell cycle by suppression of p27 and p21. Andrographolide and its derivatives, 3,19-(3-chloro-4fluorobenzylidene) and 3,19-(2-bromobenzylidene), have shown potent growth-inhibition and cytotoxicity in various cell lines. Andrographolide suppresses the progress of cell-cycle at the G2/M checkpoint in PC3, C4-2b and LNCaP cells, as well as at the G1/S checkpoint in DU-145 cells, according to a recent study. Furthermore, it has been demonstrated that andrographolide stops osteosarcoma cell growth by halting the cell cycle in the G2/M stage and it promotes caspase-mediated death. Andrographolide showed a strong anti-tumor effect in vivo with little toxicity (Wang et al., 2020).

Inhibition of Tumor Angiogenesis:

When C57BL/6 mice were injected with melanoma cells (B16F-10), andrographolide was demonstrated to suppress angiogenesis, which is specific to tumour, by decreasing the production of pro- and anti-angiogenic molecules like interleukin-2, vascular endothelial growth factor, TNF-α and NO. Additionally, it suppressed the activities of metalloproteinase 9 and angiogenesis-critical matrix metalloproteinase 2 (MMP-2) in colon cancer cells. In addition, andrographolide increased the expression of prolyl hydroxylase and hydroxyl-HIF-1 while decreasing the vascular endothelial growth factor (VEGF), suggesting that it may be used as an anti-angiogenesis or chemotherapeutic medication to treat non-small-cell lung cancer (NSCLC). In rat and hamster buccal cells, 17-hydro-9-dehydro-andrographolide suppressed angiogenesis and vascular endothelial cell growth. Furthermore, it was shown that it can be docked to the pocket of the angiogenesis-related vascular endothelial growth-factor receptor (VEGFR2) where ATP binds (Dai et al., 2017; Tundis et al., 2023). Andrographolide's mechanism of action involves inhibiting NF-κB, PI3K/AKT, STAT3 and v-Src activities, down-regulating cell cycle progression mediators, and inhibiting angiogenesis and metastasis. A new andrographolide derivative (AGS-30) has been found to exhibit anti-angiogenic properties by inhibiting endothelial cell proliferation, incursion, relocation, and tube formation. Andrographolide inhibits STAT3, PI3K/AKT, v-Src, and NF-κB activities, downregulating cell cycle progression, angiogenesis, and metastasis. A new derivative of andrographolide (AGS-30) displays anti-angiogenic properties by inhibiting endothelial-cell incursion, proliferation, tube formation, relocation, and expression of VEGF in colon carcinoma cells (HT-29). It also suppresses angiogenesis and growth of tumor in nude mice (Yadav et al., 2022).

Inhibition of Proliferation:

It has been discovered that andrographolide inhibits the proliferation of certain cancer cell lines. Research has indicated that it diminishes the viability of SiHa cells, human monocytic leukaemia and NCI-H929 cells, as well as MCF-7 and MDAMB-231, which are breast cancer cells. Additionally, it has encouraged anti-proliferative action against the human malignant melanoma cell lines C8161 and A375. Utilising the 3-(4,5-dimethylthiazole-2-yl)-2,5-biphenyl tetrazolium bromide (MTT) test, andrographolide's cytotoxic potential was evaluated. The findings imply that andrographolide may be used as a possible cancer and other cancer therapy. With an IC_{50} value of 3.7 µg/mL, andrographolide has been investigated for its anti-proliferation characteristics on colon carcinoma cells HT-29. The cytotoxicity of a group of 3,19-O-acetal derivatives was caused by the 3,19-hydroxyl groups' protection with the suitable ethylidene/benzylidene moiety, which resulted in significant anti-cancer effects (Devendar et al., 2015).

Autophagy Induction:

In numerous diseases, including cancer, autophagy—which breaks down and repairs damaged macromolecules and organelles—is an essential mechanism. It can cause death or promote survival depending on the kind and stage of the cancer. It is crucial to do research on signalling pathways connected to autophagy. It has been demonstrated that the diterpene andrographolide inhibits osteosarcoma cell invasion and metastasis by upregulation of the JNK pathway and inhibiting the PI3K/Akt and mTOR signalling pathways. It could be an effective targeted medication for fighting against cancer (Tundis et al., 2023).

Immunostimulant Characteristics:

It has been discovered that the plant *Andrographis paniculata*, which is well-known for its immunomodulatory properties, stimulates mice's “antigen specific” as well as "antigen nonspecific" immune responses, effectively defending against several infectious and carcinogens. Andrographolide acts indirectly on cancer cells by controlling the synthesis of molecules such as natural killer (NK) cells, TNF-α, IFN-γ and IL-2. Increased TNF-α production and CD expression marker result in the increase of lymphocyte cytotoxic action against cancer cells. Andrographolide inhibits the development of tumours by inducing proliferation that is induced by mitogen of bone marrow cells and increasing the generation of cytotoxic T lymphocytes, as demonstrated by in vivo tests. Andrographolide improves medical outcomes for persons having late-stage malignancies by enhancing the activity of TNF-α and NK cells when taken with other nutraceuticals (Varma et al., 2011).

Conclusion and Future Aspects:

Naturally occurring andrographolide has demonstrated encouraging anti-cancer efficacy, mostly via inducing apoptosis. It has been researched as a therapy for malignant cancer in conjunction with radiation and other medications. Presently underway initiatives concentrate on primary progressive multiple sclerosis, esophageal carcinoma, and colorectal cancer. Derivatives of andrographolide have been suggested as having higher medicinal effectiveness and less toxicity. Large-scale experiments are yet required to confirm pharmacokinetic and efficacious parameters. A number of chemical changes and nanoparticle developments have enhanced the pharmacokinetics of andrographolide.

Authors' contribution

The original concept and design of the book chapter has been done by JB and SHM. SHM and AC did article drafting. SD did review and editing.

Conflict of interest

The authors declare that they have no conflict of interest.

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Chapter- 2

Life in the Balance: Zooplankton's Battle in a Changing Environment

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Keywords: zooplankton, pollution, heavy metal, microplastic, climate change

Abstract:

Zooplankton are often overlooked but are vital components of marine and freshwater ecosystems. Zooplankton are pivotal in nutrient cycling and ecosystem dynamics as they transfer energy between primary producers and higher trophic levels. However, unprecedented growth in human population and industrialization have exposed aquatic environments to various pollutants, threatening zooplankton communities worldwide. Nutrient over-enrichment, primarily from sewage discharge and agricultural runoff, has caused eutrophication in water bodies. It is altering species composition and favouring the proliferation of certain zooplankton groups while decimating others. As a byproduct of industrialization, heavy metals have infiltrated aquatic ecosystems, accumulating in zooplankton and propagating up the food chain. It poses grave risks to human and ecosystem health. Microplastics (MPs) infiltrating aquatic environments also threaten zooplankton, impairing feeding, growth, and reproduction and altering gene expression. The emergence of pharmaceuticals and antibiotics as environmental contaminants further compounds the plight of zooplankton, disrupting reproduction, survival, and ecological resilience. Pesticides, pervasive in agricultural runoff, harm zooplankton communities significantly, jeopardizing ecosystem stability. Climate change compounds the problem in zooplankton communities by inducing range shifts and phenological changes, altering community dynamics, and heightening vulnerability to other stressors. Regular monitoring of zooplankton has emerged as an invaluable indicator of ecosystem function. As researchers strive to unravel the complex interplay of stressors reshaping aquatic ecosystems, the status of zooplankton communities can signal the urgent need for concerted conservation efforts and proactive management strategies to safeguard the ecological balance of our aquatic realms.

Introduction:

Aquatic ecosystems worldwide are under severe threat of degradation due to various anthropogenic activities (Roy et al., 2022; Das et al., 2023). The need to maintain the ever-expanding human is releasing hazardous chemicals and modifying the landscapes at an

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unprecedented rate. There is a significant focus on assessing how multiple stressors caused by human-environment interactions and climate change are altering marine and freshwater ecosystems. There is a growing interest among scientists, policymakers, governments, and stakeholders in assessing the health of species, populations, communities, and ecosystems as a whole (Patra and Madhu, 2009; Dutta et al., 2014; Mallick and Panigrahi, 2018; Biswas et al., 2023).

Zooplankton are unsung heroes of marine and freshwater food web. Zooplankton is composed of a diverse array of species with wide-ranging sizes. These animals create an energy transfer link between primary producers and higher trophic levels. Many years of research have shown that zooplankton are sensitive to minute environmental changes. In aquatic ecosystems, anthropogenic factors such as heavy metals, microplastics (MPs), pesticides, antibiotics, and pharmaceuticals significantly affect zooplankton abundance, diversity, distribution, reproduction, and development. In some studies, there is evidence of anthropogenic stressors on zooplankton gene regulatory pathways as well. The changes in zooplankton communities can also act as bioindicators of ecological stress. Zooplankton groups like rotifers, cladocerans, copepods, etc., show different responses toward different stressors. On one hand, human activities and eutrophication can promote the growth of certain types of zooplankton. On the other hand, these same factors can cause increased mortality in other species. Along with creating an adverse effect on the overall health of zooplankton, bioaccumulation of pollutants also passes the harmful chemicals to higher trophic levels. In this article, we have discussed the complex nature of the influence of several anthropogenic stressors and their effects on zooplankton communities.

Role of zooplankton in the ecosystem:

Zooplankton are the key component of any aquatic ecosystem and act as an important trophic link between producers and higher trophic levels to transfer energy and matter. Grazing of the zooplankton also serves to cycle nutrients and carbon from the microbial loop. Marine zooplankton contribute to several ecosystem services. The biggest contribution is in ecosystem-supporting services - nutrient cycling, food sources to higher trophic levels, larval recruitment to fisheries, and a refuge for various other organisms. They play a crucial role in regulating nitrogen and phosphorus cycling and controlling their availability to phytoplankton. By consuming organic nitrogen and releasing dissolved organic nitrogen (DON) through their excreta, these organisms play a crucial role in supporting heterotrophic bacterial growth and exerting control on primary production. Zooplankton also transports particulate organic nitrogen (PON) to depth via the production of faecal pallets (Steinberg & Saba, 2008)**.** Essential provisioning services include wild food and the production of fish meals. Meta zooplankton is utilized as a sustainable alternative to traditional fish feed in aquaculture, serving as a live food supplement. Certain biomedical applications are also included, especially from jellyfish. Zooplankton is involved in carbon sequestration in the deep sea by sinking faecal pellets and sedimentation of dead zooplankton. It is essential for climate regulating services. For a detailed discussion about zooplankton's contribution to ecosystem services, we encourage readers to refer to recent review articles on this topic (Botterell et al., 2023). In the context of environmental pollution by human activities, zooplankton can also be of disservice in certain instances. It is a well-established fact that a diverse range of pollutants, heavy metals included, are biomagnified through zooplankton, according to research studies. This highlights the importance of being vigilant about the disposal and management of such pollutants to prevent further harm to our environment and its inhabitants. In the following sections, we discuss the interaction of some classes of pollutants with zooplankton communities. Studies from field observations and laboratory studies are included.

Effect of nutrient over-enrichment on zooplankton communities:

Nutrient over-enrichment in natural aquatic ecosystems by sewage discharge and agricultural and industrial runoff has become a major matter of concern. The primary impact of nutrient overload is eutrophication. The excess nutrient content (especially nitrogen and phosphorus) boosts the growth of phytoplankton and algal biomass, which causes oxygen depletion and dead zone formation in the water body. These incidents may convert a top-down controlled ecosystem into bottom-up control (Fernández-Alías et al., 2022). Nutrient contamination and eutrophication decrease species richness and favor the growth of more specialized and dominant zooplankton. Eutrophication promotes the growth of cyanobacterial blooms. Cyanobacteria are considered a poor-quality food source for most zooplankton, including copepods and cladocerans, because they lack many essential lipids. Its anti-grazing traits like toxicity, size, and low nutritional value reduce the fitness of zooplankton-grazers such as *Daphnia sp.* and enhance the mortality rate (Ger et al., 2016). Contamination of water by total nitrogen, total ammonia nitrogen, nitrite, and nitrate is one of the main stressors for the zooplankton community. However, studies found that different zooplankton groups show specific responses towards specific contamination. Due to high tolerance, the diversity and abundance of rotifers (*Brachionus rotundiformis* and *Brachionus rubens)* are directly proportional to the total ammonia nitrogen content. Whereas diversity and abundance of cladocera (*Moina* sp.) and copepods (*Acartia* sp.) are inversely proportional to total ammonia nitrogen content (Yang et al., 2017). Another threat caused by nutrient contamination is the entry of harmful chemicals into the food web through zooplankton. One example is the transfer of polychlorinated biphenyls (PCB) to the upper trophic level by plankton grazer *Daphnia pulicaria* (Lynn et al., 2007). Furthermore, harmful nutrient overload may affect zooplankton's lifespan and reproductive health.

Impact of metal toxicity in zooplankton communities:

With increasing industrialization in developed and developing countries, metals are increasingly released into aquatic ecosystems. Industrial and domestic sewage effluents, electronic waste, mining and oil drilling operations, etc., are major sources of heavy metal pollution in water. Zooplankton can uptake heavy metals directly from water or via metals accumulated in phytoplankton. As they are the food for higher trophic levels, accumulated nonbiodegradable metals in the zooplankton community play a significant role in transferring toxic metals to fish and humans, leading to public health concerns. Even though some metals are essential micronutrients (i.e., Cu, Zn, Cr, Mo), higher accumulation of these can cause significant physiological problems in animals. Nonessential heavy metals, such as Pb, Hg, and Cd, are established toxins affecting numerous biological activities in animals. Thus, the trophic transfer of these metals remains a very active area of research.

Heavy metals such as Cd, Pb, Cu, Fe, Cr, As, and Zn have a significant detrimental effect on the zooplankton by abundance, population, growth, body size, egg production, and egg hatching. Industrialization near coasts has increased the discharge of heavy metals in coastal, estuarine waters. Studies from the Bay of Bengal (BoB) indicate the presence of multiple heavy metals (Ni, Cu, Zn, Pb, Fe, Mg, Co, and Cr) which have major genotoxicity in zooplankton (Thirunavukkarasu et al., 2020). In the southwest part of the Bay of Bengal, the order of metal accumulation in zooplankton was found to be in the order - Fe > Zn > Mn > Cr > Ni > Pb > Cu > Ce > La > Co > U > Cd. A strong positive correlation was found between bioaccumulation in mesozooplankton and soluble metals in water in case in case of Zn and Cr (Achary et al., 2020). At the western Bay of Bengal, heavy metal accumulation study in copepods reveals that inshore communities have much higher bioaccumulated heavy metals compared to offshore samples. Higher Pb, Cd, and Ni levels in inshore zooplankton are a grave concern. Presence of strong East India Coastal Currents in the western BoB can potentially transport the copepods with accumulated heavy metals along the Indian coastline. Thus, contaminating food webs of distant places with heavy metals (Singaram et al., 2023).

One study from China indicated that urbanization causes both nutrient and heavy metal pollution in adjacent aquatic ecosystems. Higher density and abundance of some heavy metal-resistant species of zooplankton, such as, *Synchaeta oblonga* may serve as an indicator of polluted waters near highly urbanized areas. Other species like *Keratella cochlearis* and *Anuraeopsis fissa* can indicate slightly polluted water in weakly urbanized environments (Shen et al., 2021).

Zooplankton and microplastics – junk food for the primary consumers of aquatic ecosystems:

We are living in an "age of plastics," and plastic has emerged as a ubiquitous threat to aquatic environments. In recent years, there has been an increased emphasis on the study of microplastics, which are tiny plastic particles with a diameter of less than 5mm, and their impact on the environment and human health. aquatic creatures can consume microplastics in a few ways. They may eat MPs that resemble their natural food, consume prey that has already consumed MPs, or ingested MPs while filtering feeding. Additionally, benthic creatures can take in MPs during sediment mixing. Evidence of MPs affecting different aspects of zooplankton life has emerged from laboratory and field observations involving marine and freshwater species. The chief concern is the transfer of bioaccumulated MPs in zooplankton to higher trophic levels, and if MPs impact the zooplankton community, then the potential disruption of fish communities that depend on them. MPs can affect zooplankton's feeding activity, growth, development, excretion, increased mortality, and reproduction. Higher MP concentrations in water lead to a greater intake of MPs in zooplankton (Messinetti et al., 2018). The size of MPs overlaps with the size of phytoplankton that zooplankton graze on. MPs can obstruct feeding and damage the digestive system, reducing food intake (Cole et al., 2013). The disruption of food intake affects the growth, development, and reproduction processes in a cascade. Polystyrene microbeads lead to reduced fecundity in the copepod *Tigriopus japonicas* due to failure to develop egg sacs (Lee et al., 2013). Also, in another copepod *Calanus helgolandicus*, even if egg production is not disrupted, they are smaller in size and fail to hatch (Cole, Lindeque, Fileman, Halsband, & Galloway, 2015). It is concerning that MP accumulation is detected in Arctic and Antarctic zooplankton, indicating their potential entry into the pelagic food web in those regions (Wilkie et al., 2023). The ageing of microplastics can promote greater ingestion by marine zooplankton, as shown by studies with copepods *Calanus finmarchicus* and *Acartia longiremis*. This may be due to the coating of aged microplastics with biofilms (Vroomet al., 2017). In the aquatic environment, the coating of microplastics with algal-derived infochemical dimethyl sulphide (DMS) can promote increased uptake and bioavailability of MPs in zooplankton (Botterell et al., 2020).

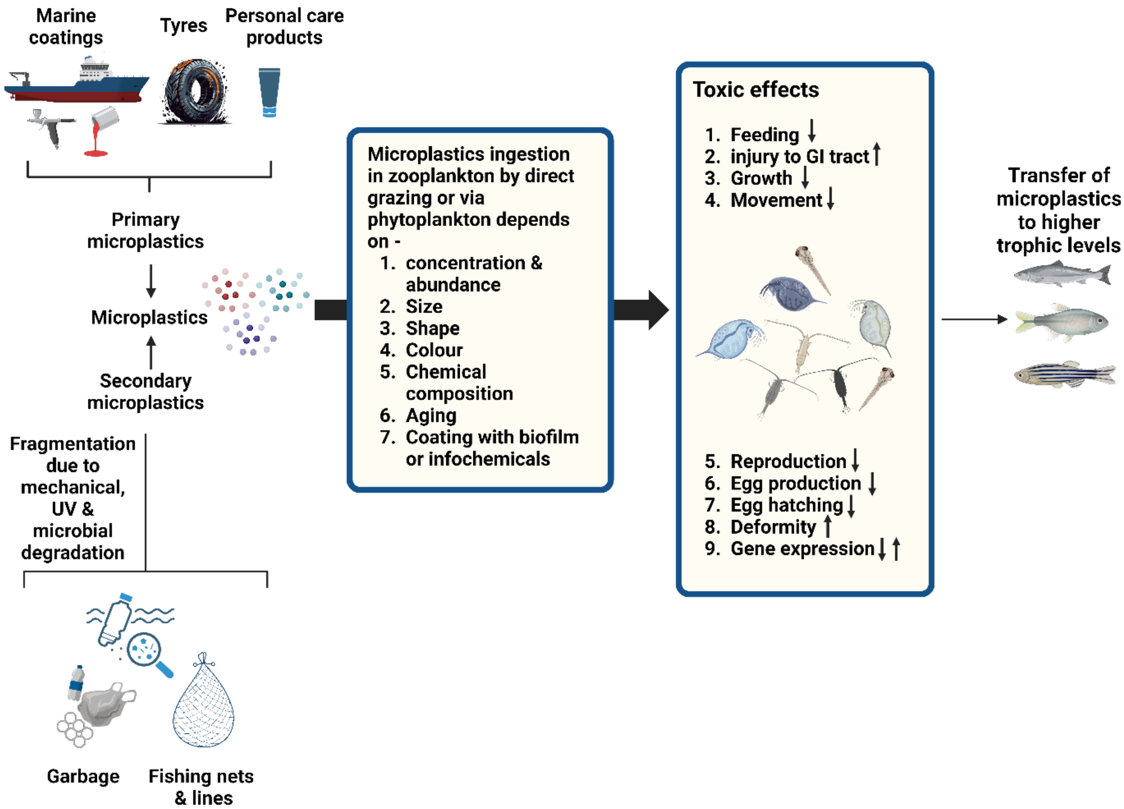

Figure 1. Negative impact of microplastics on zooplankton – Uptake of microplastic in zooplankton depends on several factors. It harms the zooplankton community via different toxic effects. Ingested microplastics can be transferred to higher trophic levels through the zooplankton. Image created with BioRender.com

At the molecular level, ethylene acrylic acid copolymer particles have been shown to alter expression levels of genes of central metabolism, oxidative stress, ovulation, and moulting in *Daphnia magna* (Coady et al., 2020). Polystyrene microbead exposure can change the oxidative stress pathways by modulating thioredoxin reductase (TRxR) and arginine kinase (AK) genes (Tang et al., 2019). Microplastics can be converted into nanoplastics in the environment, and they are potentially even more bioavailable. A recent report of rotifers converting microplastics into nanoplastics has raised concerns about the contribution of zooplankton to aquatic nanoplastic pollution (Zhao et al., 2023). A summary of impact of microplastics on zooplankton is represented in figure 1.

Antibiotics and pharmaceuticals as newly emerging pollutants affecting zooplankton:

Anthropogenic activities have released various emerging concerns (CECs) into the environment. Among them, a growing body of work indicates the presence of antibiotics and other pharmaceuticals in aquatic ecosystems. The primary sources of antibiotic contamination in aquatic ecosystems are from human and veterinary use, administration in aquaculture, and intense animal farming. Their concentrations are high enough to cause adverse effects on the resident zooplankton. Analyses suggest that bioaccumulation and biomagnification in the planktonic food web are possible for contaminant antibiotics such as tetracycline, oxytetracycline, roxithromycin, lomefloxacin, ofloxacin, etc (Tang et al., 2020). Antibiotics can also cause dysbiosis of gut microbiota in zooplankton. Many researchers have used Daphnia magna as a model organism to study the effect of antibiotics. In these zooplankton, tetracycline has been demonstrated to diminish reproduction and abundance. In the absence of adequate food, the toxicity of this antibiotic is increased (Akbar et al., 2020). Due to norfloxacin exposure, heartbeat rate and feeding efficiency were decreased in *D. magna*. It increased the time ratio of vertical to horizontal swimming (TVH) and the duration of quiescence (Pan et al., 2017). Lomefloxacin is also recorded to cause oxidative stress-induced cellular damage in these animals (Luo et al., 2018). Sometimes, multiple antibiotics are detected in aquatic ecosystems. To model such scenarios, Daphnia magna was exposed to a cocktail of antibiotics (aztreonam, erythromycin, and sulfamethoxazole), which decreased the associated microbiome diversity (Cooper, Tjards, Rischling, Nguyen, & Cressler, 2022). There are reports of other antibiotics and pharmaceuticals hampering density, reproduction, and survivorship in rotifers as well (González-Pérez et al., 2016; Wang et al., 2017). This is a newly emerging field of study, and further research is necessary to unravel the complex interactions antibiotics can have on zooplankton.

Disruption of zooplankton communities by pesticides:

Pesticides have become widespread contaminants in aquatic ecosystems. Wetlands close to agricultural fields are worst affected due to agricultural discharge, runoff, and drift of pesticide sprays. Scientists relied on laboratory-based studies utilizing model organisms (i.e., *Daphnia* sp.) to study the LC50 values and life history, physiological and behavioural effects.

Worryingly, relatively newer pesticides, such as imidacloprid, which is favoured for low toxicity in vertebrates and short environmental persistence, have been shown to disrupt zooplankton in water bodies. Feeding activity is significantly reduced in *Daphnia magna* even at sub-lethal concentrations of imidacloprid. This may be due to abnormal motility to avoid the substance and higher metabolic costs to detoxify it (Pestana et al., 2010). Zooplankton such as cladocerans, copepods, and rotifers produce egg banks as dormant stages to overcome adverse environmental conditions. They are deposited in the sediments and stay there till hatching under favourable conditions. The application of glyphosate-based pesticides has been documented to impair emergence from egg banks and reduce zooplankton diversity (Gutierrez et al., 2017).

Currently, a complex mixture of insecticides is present in affected water bodies, and researchers are focusing more on community-level disruptions. One study found 29 different pesticides in a lake associated with declining abundance of metazoan zooplankton. Chlorpyrifos and cypermethrin were the main culprits identified to cause this decline (Kong et al., 2022). Long-term studies indicate that insecticide mixtures can continue to impact natural systems for several weeks, even after they are no longer detectable in water (Hasenbein et al., 2016).

An exciting area of research is the emergence of pesticide resistance in zooplankton. Pesticide resistance is of grave concern when it is found in the target pest species. However, research has shown that if a population of zooplankton in a community is resistant to pesticides, then it helps the community to be resilient towards that contaminant. One study showed that if a *Daphnia pulex* population resistant to AChE-inhibiting insecticide chlorpyrifos is present in an aquatic community, it may help to maintain the community dynamics even when exposed to other similarly acting insecticides (i.e., malathion, carbaryl). Mesocosms with insecticide-sensitive *D. pulex* populations experience phytoplankton blooms after exposure to insecticides. This was avoided if resistant *D. pulex* populations were present. If sodium channel-inhibiting insecticides (i.e., permethrin, cypermethrin) are added, it leads to a reduction in the abundance of both chlorpyrifos-sensitive and resistant *D. pulex* populations (Hasenbein et al., 2016). Future studies should focus on insecticide-resistant zooplankton populations in natural freshwater and estuarine ecosystems.

Climate change and zooplankton – web of complex interactions:

Over the past decade, accelerated climate change has threatened to drastically alter the aquatic system's environmental parameters, which greatly impacts zooplankton. Climate change imparts changes in marine ecosystems through different mechanisms. The structure of the zooplankton community is influenced by the warming of the upper layer of the ocean, which affects the process of nutrient enrichment and water column stratification. Under well-mixed cold water conditions, the surface layers are supplied with nutrients that favor the population of large copepods. But in warm stratified waters, nutrient supply to surface layers is hampered. This favors the zooplankton community being dominated by jelly fishes, ctenophores, salps, etc. (Richardson, 2008). Range shift is documented in calanoid copepods of North Atlantic Ocean. They are shifting northward at a rate of 23.16 km/yr due to rising sea surface temperatures (Gregory et al., 2009). It is important to note that these shifts are not consistently observed, and they vary significantly in strength and direction, often being specific to a particular species. A consequence of warming ocean temperature is attributed to the advancement of zooplankton phenology. Global warming is causing earlier peak zooplankton abundance mainly due to the advancement of spring. For instance, the biomass of *Neocalanus plumchrus*, copepod found in Subarctic Pacific Ocean, is peaking 73 days earlier per 1°C rise in temperature (Ratnarajah et al., 2023). Ocean acidification is another great concern. Even though copepods were thought to be resilient to ocean acidification, new research has suggested that the nauplii stages of their life cycle suffer higher mortality due to acidification (Cripps et al., 2014). Copepod *Centropages velificatus*, when exposed to simulated thermal stress of heatwave, were found to have higher mortality and reduced egg production. This thermal stress also made it more susceptible to anthropogenic stressors such as oil spills (Hernández Ruiz et al., 2021). Freshwater zooplankton are also not spared from the ill effects of climate change. Frequent and increasingly intense heat waves are a clear sign of climate change. When phytoplankton are cultured under heatwave conditions, they cannot nourish freshwater zooplankton (Kim et al., 2024). The influence of climate change on zooplankton dynamics is a multifaceted phenomenon. Scientists are engaged in documenting the changes already happening in zooplankton communities and trying to model future changes.

Conclusion:

Zooplankton communities in marine and freshwater ecosystems face diverse anthropogenic stressors, which are only increasing in intensity. Globally, evidence of considerable changes in abundance, distribution, and physiological and behavioural alterations in zooplankton is being reported. Scientists are constantly striving to study the effect of environmentally relevant concentrations of toxicants on zooplankton dynamics. The situation is even more complex as zooplankton in a particular place are exposed to various stressors belonging to different categories. What impact these assemblages of stressors have on zooplankton is slowly being revealed. Zooplankton is reported to accumulate both heavy metals and organochlorine pesticides, simultaneously providing a pathway for the movement of these toxicants to other organisms (Basu et al., 2021). Warming waters can influence the effect of other toxicants. Increased temperatures can prolong the long-term adverse effects of pesticides in *Daphnia* sp. (Knillmann, Stampfli, Noskov, Beketov, & Liess, 2013). The presence of pharmaceutical contaminants can enhance the derogatory impact of climate change in freshwater ecosystems (Duchet et al., 2024). Climate change can alter the exposure of marine species to microplastics by disrupting their reproductive cycles and behaviours (Haque & Fan, 2023).

Monitoring every single species in an ecosystem is practically impossible. As a result, it is beneficial to develop zooplankton bioindicators that can be used to assess the status and trends within ecosystems (Burger, 2006). Zooplankton plays a crucial role in the ecosystem, yet it is rarely utilized commercially. This unique characteristic, combined with the fact that it can reflect the impact of various environmental stressors, makes it an ideal candidate for the role of a bioindicator. Consistently monitoring zooplankton is extremely valuable for planning and evaluating the outcomes of conservation efforts.

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Chapter- 3

Sustainable Basic Science: New Avenues in Vector Biology and a Novel Artificial Intelligence Paradigm for Research in Public Health

Bishnu Goswami* and Ashis Kumar Panigrahi

Keywords: hotspot, physicochemical, analysis, software, public health, mosquito, basic science

Abstract:

Sustainable research in basic science can be effected more fruitfully with an interdisciplinary scope with a focus on the needs of the general public and penetration to the rural and semirural users, especially in contexts such as public health. Here we have utilised a software based approach for detecting hotspots to curb the menace of mosquito borne diseases. The software module utilises Bongojontro Baksobandi software which was used extensively in past research. The highlights include scopes for incorporating transferable skills to its users, in addition to its primary role in basic research. The initial impression of using the software by high-school users of a rural school and local National Service Scheme (NSS) volunteers was very positive. Future proposals include the use of Artificial Intelligence (AI) models and a pedagogy paradigm for the future learners and researchers.

Introduction:

There are a number of hindrances in the way of sustenance of research in basic science. Although basic science as a subject of graduate study and further research still holds very high acclaim and eminent prizes such as the Nobel prize are given to exceptional researchers, there are still significant problems, such as a gender divide (Tripathi, 2022) and a broader problem with STEM courses and on the topic of the inclusion of minorities (Alexander, 2009; Matz, 2017). Some work, however, is being done to minimize such gaps through inclusive and equitable practices (White, 2021) and using a "systems thinking" approach (Mahaffy 2018).

Developing and newly industrialized countries, one example being India, have additional challenges. These challenges include the lacunae in the development of vocational studies in India, which often contains parts of the subject of basic science, compared to countries like Australia (Sharma, 2018). Secondly, but perhaps no less importantly, there is a need for improved training in public health in India (Tiwari, 2018). Targeting the population itself, even

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using sophisticated approaches such as algorithmic seeding of social networks, has been tried in at least one of the largest cities in India (Alexander, 2022). However, there are still lots of gaps to fill, especially when the rural and semi-rural parts of the country are to be considered.

In the context of the enemy of mankind, perhaps nothing strikes as more ominous and terrifying than the mosquitoes. Each year, the disease Malaria itself kills over one million people worldwide (Madhu and Sarkar, 2015; Sil et al., 2016; Madhu, 2018; Mubarick, 2021), and mosquitoes are responsible for over one billion cases of diseases in humans (Alar, 2021). One of the most viable ways to reduce the menace of mosquitoes is to target the larval stages of the insect, and various approaches, both physical and chemical have been used, extending in very advanced ways such as oil-based nanoformulations (Esmaili, 2021).

Our research aims to address these three broad areas. The first is to make basic science research more accessible to the masses and rural areas. The second is relating this research to public health so that every stakeholder can potentially benefit. The final is how to facilitate the research in the specific physicochemical analysis keeping the first two areas in mind. The latest development from our research is in the creation of hotspots for physicochemical analysis using a software-based approach. Finally, we're introducing a novel AI paradigm fit for the masses and the future.

Methods:

Making basic research more accessible to the masses, so that they can take up research in their career as an option, or more generally, increase the general awareness about science, is not exactly rocket science. But it is not very simple either. If we consider Maslow's hierarchy of needs, the literature mentions that before a student's cognitive needs can be met, they must first fulfill their basic physiological needs (McLeod, 2007). Before the finer aspects of self-actualization atop the pyramid are met, which research is arguably a part of, the cultural and family expectations need to be met. In many developing and newly-industrialized countries, pressures from the family and local culture come in the way of career selection (Ali, 2017). A common theme among those pressures is the requirement to learn skills that will be useful for the individual's career and for the older members of the population, skills that are directly transferable to career benefits. Amidst this situation, drives such as basic science exhibitions, one-off workshops, and public lectures suffer from the possibility that the intended penetration of their goals will be not met. Unlike specialists, professionals, and students, the interest in research activities is often not a priority for the masses.

Keeping the above paragraph in mind, we had previously developed Bongojonto and Bongojontro Baksobandi, two software modules for general and applied programming and their use by non-programmers. The latter supports various modules that can be used in public-health scenarios (Goswami, 2022). In the latest work, we are using it to detect hotspots for succeeding physicochemical analysis.

As touched upon in the introduction, the larval stages of mosquitoes are easier to neutralize than other stages. These larvae are found in patches, or hotspots, mostly in and around human habitats. A significant part of the work in vector-borne disease biology is to record the physicochemical parameters of the water bodies in the hotspot zones, and detecting which ones are the hotspots for further analysis can be cumbersome for work in larger areas and for multiple seasons. Here our new module in Bongojontro comes in handy.

Figure 1. With one year/season's data, the model predicts hotspots for the next year or season for physicochemical analyses

Based on database entries of the previous year's larval sampling in the region and on the chemical analysis of the hotspot's water bodies, the module predicts the next year's (or later years, with reduced accuracy) hotspots (Figure 1). These physicochemical analyses, which include temperatures, turbidity, TDS, and concentration of various cations and anions are done by hand using sampled water from the water bodies. Often, the number of water bodies in the study region is too numerous, which makes the work difficult for non-specialists or short-duration research initiatives. In those cases, this hotspot detection software has the potential to be very useful.

The hotspot detection algorithm is based on linear regression models and in the future, we wish to incorporate more advanced machine learning and artificial intelligence models based on even more inputs. We are using a simple linear regression model for now and testing out their usefulness in hotspot detections and succeeding eradication of mosquito larvae to curb the deadly diseases carried by the mosquito vectors.

To impart useful skills and career opportunities, the latter for students, we have incorporated useful skills for a better career in Bongojontro and Bongojontro Baksobandi from the get-go. These include the support of regional languages such as Bengali so that first-time learners can use it. Secondly, the syntax of programming in Bongojontro Baksobandi's modules is such that its users can easily switch to a more established language such as Java or JavaScript (Figure 2). Elaborating on these factors during the demonstration of our software in the context of vector-borne disease elimination proved to be very helpful, at least for the survey participants we had the chance to be with. These characteristics of the modules make it more enticing for the students and adult participants as they can learn transferable skills from the software which extends much beyond a single-case basic science analysis or applied biology and health analysis.

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Anopheles");
rog = `nau_lekha("Elekai
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dekha
jacche?","Dengue");
bektiguto = `nau_lekha("Bektigoto surokha","Ki ki bektiguto surokha nan moshar
birrudhe?","Mosari");
```

Figure 2. A sample program from the Bongojontro Baksobandi module showcasing its simple structure and the transferability of its users to more established languages

Secondly, we introduced a paradigm for the use of AI in vector biology research. With our focus on incorporating a large section of society, and learners in particular, it was realized that restricting ourselves to the advanced aspects of AI was incomplete by itself. Therefore we made a four-tiered AI paradigm in order of the skills of the workers. These tiers were:

Tier 1- Identification of genera and working in the breeding grounds: Fit for inexperienced adults with a short training period and younger students or volunteers. Most useful in developing or newly industrialized countries. Work under this tier includes the collection of larvae of specific genera (associated with spreading mosquito-borne diseases) and live procurement of them to the laboratory.

Tier 2- Creating training datasets: Fit for high school students of science and college students. AI-associated predictions and modelling depends (in most practical cases in the context of vector biology) on creating good training data. Work under this tier includes controlling of the light and environment and the use of smartphones to capture videos of mosquito larvae.

Tier 3- Laboratory work: Fit for undergraduate and graduate students: These usually require a dedicated laboratory environment where precise control of the environment is necessary to grow the larvae or study their various dynamics. Opposed to smartphones, which tend to have over-eager processing, regular cameras (DSLR, Mirrorless or specialised scientific ones) can be used. These are restricted to this higher tier as they have bigger upfront costs compared to smartphones, which are already in circulation and thus, no or little extra cost is needed for their use in vector biology contexts.

Tier 4- Advanced Laboratory work: Fit for research scholars or scientists: These require a laboratory setting and higher experience. Under this tier, work can include working with Convoluted Neural Nets (CNNs)(Promising for larval identification by AI means) and proper utilisation of training and test sets. It was hypothesized that the four tiers can work together in a joint interdisciplinary venture between the students, researchers, various governmental and non-governmental organizations and the common people who suffer from biological vectors like mosquitoes.

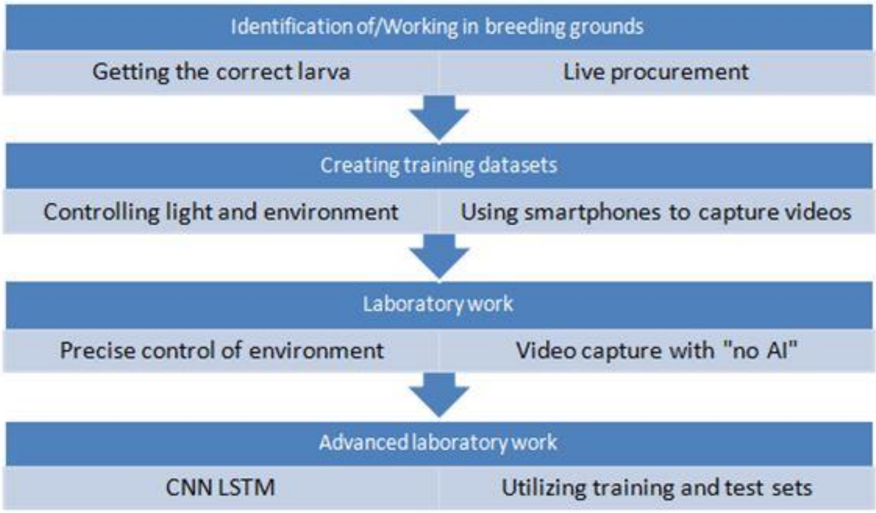

Figure 3. The AI paradigm with increasing levels of sophistication which was introduced to the survey participants

Result & Discussion:

Schoolchildren of the age group 15-17 from a local school and National Service Scheme (NSS) volunteers of India who had previously worked in public health were taken as volunteers and were introduced to the new module and were surveyed on their reception of the software module for in-field usefulness. The total number of survey participants was 56. A survey instrument called the USE questionnaire by Lund (Lund, 2001) was used. Overall, the responses were very positive and hint that further work along these lines can be very fruitful.

Diseases transmitted through vectors present a major concern to human health, hence affecting various parts of the world that are hostile to vectors. The two generic forms of controlling these diseases IRR include insecticides and bed nets, which also have their shortcomings in that they are havoc to the environment besides exerting a high level of resistance. But since their re-emergence, there has been increasing focus on studying their biology and identifying prevention and control strategies that are sustainable. In terms of vectors, one course is devoted to the study of ecology and behaviour (Thiruvoth and Pulikotil, 2017). Scientists noted that comprehending the different factors that affect vector ecology, such as abundance, distribution, and host choice, can help in implementing a focused control strategy. For instance, understanding the mating preferences and behaviors of mosquitoes and their dependence on other species in their environment may inform fledgling techniques that erode their breeding capability. Finally, in what is probably the greatest development thus far, growth in the fields of molecular biology and genetics brings about new means of vector manipulation. Applying genetic modification through such technologies as CRISPR-Cas9 lets potentially develops sterile or disease-non-transmitting mosquitoes, as well as increasing their susceptibility to control agents. However, ethicists hold that certain parameters should not be crossed, and what impact on the environment in particular could entail is still unknown. Indeed, it is possible to define this paradigm as an efficient theoretical and practical framework in public health empowered by means of appropriate AI tools that may fit the needs and concerns of investigators involved in the public health research process. For example, machine learning algorithms can be trained for surveillance of epidemiological data and derive possible incidences of diseases, thereby enabling authorities to respond promptly.

Also, through the consolidation of information obtained from multiple sources, such as notes on patients, environmental information, and social media posts, AI can offer a broad view of the health status and its causes. The use of big data and related predictive modelling allows the researcher better to understand the high-risk population and direct public health resources most effectively.

Table 1: Part of the results we obtained from the survey.

Statement	Score (1-7)	Standard Deviation
It helps me be more effective	6.02	0.84
It helps me be more productive	4.88	1.23
It is useful	6.26	1.02
It makes the things one would want to accomplish easier to get done	6.14	1.06
It saves me time when I use it	5.18	0.79
It is easy to use	5.06	0.95
It is simple to use	4.35	1.11

Conclusion:

Sustainable basic science research is in high demand for the growth of GDP and other human growth indices throughout the world. However, to reach the masses, both as future researchers and as facilitators of research, requires a more thorough approach. In our work, we have demonstrated that a preliminary software based module can be used for public health research while imparting transferable basic programming skills to its users. The choice of sample collection grounds for chemical and physical analysis was the highlight of our latest Bongojontro module. The initial survey on usability of the software also returned very promising results. In the future, we wish to further explore the interdisciplinary scopes of furthering basic science and scientific research in general. In the context of AI, in the future we are hopeful that better models can be developed which can ensure high accuracy and can be used in conjunction with drones. Although the problems of increasing niches of vectors such as mosquitoes are likely due to global warming, the application of a sufficiently "intelligent" AI holds the promise for a bright future!

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Chapter- 4

Ornamental Fish Culture: A Way Towards Sustainable Development and Alternative Livelihood for West Bengal Fisherwomen

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Keywords: Ornamental Fish, West Bengal, Ornamental Fish culture, Alternative Livelihood, Women Empowerment

Abstract:

The ornamental fish trade sector is gaining importance since past few decades. Demand for aquarium fish in both domestic and international markets is increasing constantly. India is rich in the biodiversity of freshwater and marine ornamental fishes but its contribution to the international trade is significantly low compared to the demand. Three main states contributing to the export of ornamental fish are West Bengal, Kerela and Tamil Nadu out of which West Bengal is the leading state. Still many fishermen community in the state are economically backward since they don't earn sufficient from fishing and many have to opt for other income sources like labour work. In this scenario, breeding and culture of ornamental fish could be a very good alternative source of income for these fishermen. Ornamental fish culture requires very little space, low investment and little labour force. This culture can also be done in the house's backyard in small circular or rectangular tanks. Since it can be done easily in the house with minimum labour, women can also engage in this activity and make a remarkable contribution towards this business. It can also provide them with financial stability. Proper and scientific ornamental fish culture will not only increase the rate of export and gain foreign exchange but also promote women empowerment in financially backward areas.

Introduction:

Ornamental fishes, also known as aquarium fish, are referred to the small-sized, beautifully coloured, peaceful-natured fishes that are kept in the aquarium for aesthetic, educational and decoration purposes. Due to their beautiful appearance, they are sometimes also called "Living Jewels" (Dey, 1996). Singh, 2005 reported that ornamental fish are the most common pets in the world and keeping aquarium fish in the house is the second most popular hobby after photography (Singh, 2005). Some ornamental fish also attract the eyes of the aquarist due to their interesting behaviour, like tail wagging, down crawling, sudden rise and fall movement,

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and change of colours at different times of the day (Basu, 2012). Ornamental fish include both marine and freshwater fishes.

India has a rich diversity of many ornamental fish species. The two global hotspots of freshwater biodiversity of the Indian subcontinent i.e., 'The Western Ghats' and 'The North-Eastern region' have a huge abundance of the freshwater ornamental fish. North East alone has reported 266 species of freshwater aquarium fish out of the total 806 species from India. The North Eastern lakes, reserviours and hill streams are home to some of the prominent Indian freshwater ornamental fish like barbs, catfish, eels, loaches and goby (Mondal, 2017). The Western Ghats consist of 155 species of ornamental fish, out of which 117 are endemic to that area. Apart from the northeastern states and western ghats, other coastal states like West Bengal, Tamil Nadu and Kerala are also rich in many species of indigenous ornamental fish. Therefore, India can be rightly regarded as the "Gold Mine" of freshwater ornamental fish (Talwar and Jhingran, 1991).

The state of West Bengal has over 288 species of exotic ornamental fishes. Freshwater ornamental fish include *Amblypharyngoden mola* belonging to Cyprinidae, *Anabas testudineus* from Anabantidae family, *Alia coila* from Cyprinidae, *Brotia derio* from Cobitidae family, *Channa fasciata*, belonging to Osphronemidae (Basu et al., 2012).

Table 1: Some common freshwater ornamental fish species of West Bengal with their families.

s.no.	Common name	Scientific name	Local name	Family
1.	Rosy Barb	*Puntius conchonius*	Kanchan pungti	Cyprinidae
2.	Mola Carplet	*Amblypharyngodon mola*	Maurala	Cyprinidae
3.	Black Knife Fish	*Notopterus notopterus*	Pholui	Notopteridae
4.	Golden Cat Fish	*Mystus tengra*	Tengra	Bagridae
5.	Spotted Snake Head	*Channa punctatus*	Lata	Channidae
6.	Indian Glass Fish	*Pseudoambasis ranga*	Ranga Chanda	Ambassidae
7. **8.**	Gulper Cat Fish	*Ompok pabda*	Pabdah	Siluridae
9.	Indian Chacca	*Chaca chaka*	Chacca	Chacidae
10.	Leaf Fish	*Nandus nandus*	Nadosh	Nandidae
11.	Spiny green eel	*Mastacembalus puncalus*	Pankal	Mastacembel idae
12.	Striped dwarf catfish	*Mystus vittatus*	Tengara	Bagridae
13.	Gangetic scissor tail	*Rasbora rasbora*	Rasbora	Cyprinidae
14.	Long whiskered catfish	*Aorichthys aor*	Aar	Bagridae
15.	Indian tiger shark	*Pungassius pungasius*	Pungas	Siluridae
16.	Guntea loach	*Lepidocephalus guntea*	Gunte	Cobitadae
17.	Stri17.pped gourami	*Colisa fasciata*	Khalisa	Belonidae

History of Aquarium Keeping:

The earliest history of fish keeping dates back to 960-1279AD when the Sunga Dynasty ruled China. The rulers used to keep Goldfish in small tanks and ponds for recreational purposes. Goldfish is regarded as the first ornamental fish. In 1616AD, goldfish arrived in Japan and subsequently in Europe and Portugal in 1691AD and England 1728AD, respectively. Thereafter, breeding of the fish in captive conditions began to be emphasized and Holland became the first country in 1780AD to successfully breed the goldfish. Later on, goldfish started gaining popularity across the world and people started to consider a more sophisticated and efficient container in which the fish could survive longer.

Robert Warrington is credited as the first designer of the aquarium. He built square-shaped box made of glass and filled it with sand, snails and plants to create an ecosystem for the fish to survive. Using this method, aquariums were successfully established during the 1950s (Novak et al., 2020).

Few benefits of ornamental fish:

Ornamental fish keeping has many positive effects on the health and life of people. Some of them are described below:

- It stabilizes the blood pressure by triggering the GABA neurochemicals in the central nervous system, which inhibits the nerve transmission responsible for causing anxiety (Smith 2014).
- Huachinago, 2013 concluded that viewing these beautiful creatures can benefit the eyesight (Vargasmachuca et al.,2013).
- Gazing at the aquarium can release endocannabinoid, which is a neurochemical responsible for causing a sudden sense of happiness (Senske, 2019).
- Apart from the medical benefits, keeping an aquarium in the house can enhance the look of the interior and also help in children's education.

Ornamental fish trade:

Ornamental fish trade and the industries associated with it are a major source of overseas income, especially in tropical countries like South America, Africa and South East Asia (Andrews, 1989). The major exporting countries of ornamental fishes are Sri Lanka, Malaysia, Hong Kong, Indonesia, Thailand and India. Mostly, freshwater fish are traded, which contributes to almost 90% of the trade value profit and, whereas the marine ornamental fish accounts for the rest 10% (Lem, 2001). Generally wild fishes are harvested for ornamental fish trade, but a few, around 1-10%, are also bred in captivity (Wabnitz et al., 2003). Some of the ornamental fish with high market value include *Ctenochaetusn havaiiensis*, *Centropyge potteri*, *Z. flavescens* and *Acanthurus achilles* (Wabnitz et al., 2003). The trading of ornamental fish involves many people in different steps. The first step includes breeders, then wholesalers, and at last, retailers and consumers.

Larkin 2003, Wabnitz et al., 2003, Pelicice and Agostinho 2005 and Prang 2007 concluded that trade consisting of aquatic organisms is likely to become a multibillion-dollar industry in the recent future and ornamental fishes can form the most valuable fishery commodity on the basis of unit weight (Hardy, 2003). The trade consisting of aquarium fishes has diversified since the last four decad. These fishes are receiving increased attention due to the increase in their global and local demand. The trade related to ornamental fish is only 0.5% of the total fish trade in the international sector, but it plays a crucial role in providing employment and income opportunities to the developing countries (Monticini, 2010). Nammalwar 2008 concluded that due to their wide geographical spread and extensive species diversity, the ornamental fish business can be a promising field in the aquatic business sector (Nammalwar, 2008).

National status

The ‘Food and Agricultural Organisation (FAO) reported that the live fish exports from India increased from US$ 21.5 million to US$ 315 million in the year 2007 (Monticini 2010). This includes both food fish and ornamental fish. Bojan, 2005 reported that India traded around 7 lakh value of ornamental fish in the year 2003-2004 (Bojan, 2005). India exports ornamental fish to the countries like Belgium, China, South Africa, the United States, United Kingdom and Singapore. About 90% of the aquarium fishes are exported from Kolkata, whereas Mumbai and Chennai export 8% and 2% respectively (Felix, 2009). Domestic trade value of aquarium fish in the Indian subcontinent is roughly around 10 crores annually, and it is increasing at the rate of 20% per year, the demand being much higher than the supply (Vinci, 1998; Madhu et al., 2022). Therefore, it is an excellent opportunity for business due to the strong demand for ornamental fish from domestic and export markets (Elamparithy, 1996).

Status of ornamental fish trade in West Bengal

West Bengal has so far reported 176 indigenous varieties of ornamental fish that can be well-bred in captivity (Mahapatra and Larka, 2012). The state leads India in the trade of aquarium fishes, generating an export value which is almost 50% share alone of the total export value generated by the whole country (Mahapatra et al., 2004; Dhara et al., 2016). The two major districts of West Bengal which are involved in the production and trade of ornamental fish to the international market are Howrah and South 24 parganas. Five community development blocks, namely Jagatballavpur, Panchla, Sankrail, Domjur, Jagacha, Falta, Budge Budge I and II, Bishnupur I and II and Magrahat I and II have ornamental fish trade (OTF) operations. Other districts of West Bengal having OTF operations include Nadia, Murshidabad, Hoogly, East Midnapore and Jalpaiguri. Domestic wholesale markets of the state are in Das Nagar, Howrah and CTI Bazar (Banerjee et al., 2019; Mukherjee et al., 2022). Following flowchart represents the distribution pattern and supply chain of ornamental fish in West Bengal.

Ornamental fish culture: An alternative livelihood source:

Ornamental fish culture and marketing are gaining importance day-by-day and are helping many rural and semi-urban fish farmers to earn their livelihood. The ornamental fish business in the developing rural area can promise a potent source of livelihood for many poor people as it can generate more employment opportunities, alleviate poverty, slow down urban migrations and also contribute the national income growth. This can promote equal distribution of income across the rural fishermen and fish breeders and can also enhance foreign exchange (Anon, 1979). The aquarium fish trade is considered 100 times more profitable compared to food fish. Belton and Little 2008, World Bank 2006 mentioned that the culture of aquarium fish can promote a sustainable alternative source of income. But, the involvement of local fishermen and women in the breeding and culture of ornamental fish is very low. Dey (1996) surveyed the five topmost ornamental fish exporting states, namely West Bengal, Kerela, Karnataka and Tamil Nadu, through census sampling and found that the ornamental fish workers were roughly around 2000 in number (Griffith and Cramp, 1998). Though the ornamental fish trade business has generated significant employment opportunities over the last 15 years, there is no proper symmetry between the collectors and wholesalers. The margin of the fish farmers and fish breeders is significantly low than the collectors.

West Bengal is blessed with many freshwater bodies like rivers and ponds, while estuarine water bodies line many coastal districts of the state. These water bodies are home to many fishes and therefore, fishing forms an important source of income for many rural fishermen. But, the unavailability of proper infrastructural facilities, low education, lack of awareness and improper marketing strategies have rendered them to suffer from social and economic backwardness. The economic condition of some fishermen is so poor that they are not even able to purchase proper technical gadgets for fishing and have to depend on handmade nets, gill nets and cast nets to catch fish. Bhoumik and Pandit (1994) discovered that many fishermen have to depend on other income sources like working as labour or rickshaw pulling during the offseason in order to feed their families and meet their needs, which do not fetch them much profit (Bhoumik and Pandey, 1994). Culture and farming of ornamental fish can be a promising alternative income source since it can be carried out with very little investment using integrated system (Belton and Little 2008). Moreover, breeding, culture and farming of ornamental fish is possible on a small scale which can enable small entrepreneurs to start small-scale setups (Raja et al., 2014). Therefore, more fish farmers should be motivated towards this business.

Role of fisherwomen:

In India, about one-third of the labour force consists of women. Therefore, their socio-economic empowerment cannot be neglected. India consists of 5.4 million active fishers, out of which 1.6 million are fisherwomen (Qureshi, 2013; Dutta et al., 2014). Women have made immense contributions in the field of fish sorting, processing and marketing of the fish. They also do sorting, gutting, net mending, loading and icing of the fish. Harper et al. (2017) mentioned the employment of women in the fisheries sector sine times immemorial. These women support their house economy by involving in the possible fisheries sector areas. Women contribute to 58% of the activities like mending of the nets, making feed, and also selling the produce (FAO, 2020).

Goswami 2011 found the ornamental fish culture to be a very suitable livelihood opportunity for women as it can be easily performed under small scale (Goswami 2011). And women are fortunately showing interest in this sector. A training programme conducted on Dakshin Dinajpur on the theme of "Ornamental Fish Breeding and Culture" witnessed more than 40% of women trainees who actively participate in the programme (Goswami and Dana 2012). This indicates that on being given the right opportunities and facilities, women from the rural fisherwomen communities can start earning decent livelihood income.

Sundarbans is dotted with many species of mangroves. The water bodies associated with it boast of huge biodiversity of ornamental fishes. Sundarbans have recorded 67 species of ornamental fishes (Mondal et al., 2012). Majority of the people are economically backward and depend solely on the localised earning or on a single source of income. In this scenario, ornamental fish culture and trade could be very beneficial for them as an alternative source of livelihood. The fisherwomen sector of the Sundarbans can also opt for ornamental fish culture as it can be easily done in a house backyard with very little space requirement and minimum investment (FAO 2004). Thus, aquarium fish culture can prove to be a promising way of earning for these women, which can ultimately contribute to women's empowerment.

Role of the Government to Promote Ornamental Fish Culture:

The Government of India and West Bengal can play a very crucial role in promoting the culture of ornamental fish. Government has taken many schemes such as the "Pradhan Mantri Matsya Sampada Yojna (PMSSY)" which has generated almost 7 lakhs employment under this field; "Swarna Jayanti Gram Swarojgar Yojna (SGSY)" that emphasizes on the economic activation, social mobilization and formation of self-help groups (SGH). The ICAR-CIFA (Indian Council for Agricultural Research- Central Institute of freshwater Aquaculture) have developed many breeding culture techniques, especially for the indigenous ornamental fishes.

Discussion

The trade of ornamental fish has diversified since the last four decades. Most of the ornamental fish farmers generally rely on the captured fish for marketing. But unplanned and vigorous catching of these fishes could lead to a decline in their population which may threaten their species. Moreover, since the market demand for these ornamental fishes is far exceeding the supply. There is a need for the breeding and culture of these fishes. The breeding of the captive fish can be performed with very low investment and labour. Proper brood stock management should be done which enables the fish to produce large numbers of fertilised eggs. Most ornamental fish farmers generally rely on wild fish feed, but due to the rising demand, which is creating pressure on the production rate, there is a dire need for the commercial. For this, the nutrient requirements of fish should be known. Proper network between the fish breeders and stakeholders may also help in smooth marketing practices. Active involvement of the women in this sector can play a very crucial role in their empowerment. The government should organise periodic training like breeding of fish, packaging and transportation, fish disease management, cluster development, scientific procedures related to the management of fish farms, entrepreneurship and marketing. Breeders who follow good practices should be awarded.

The Government of India should take the necessary steps to promote the culture and trade of ornamental fishes. Sundarbans have recorded nearly 67 species of ornamental fishes, which is a poor number as compared to the rich biodiversity of the area. The Government should motivate more taxonomic researchers to identify any potential new species of ornamental fish and promote them for culture and trade. This would generate more employment opportunities for the young rural fisherwomen and motivate them to engage in the ornamental fish culture and business sector actively.

Conclusion

Ornamental fish trade is gaining importance day by day in both national and international market. Due to huge demand and low supply, a greater number of fish farmers, especially the fisherwomen should actively engage in this field. Sundarbans district of West Bengal has many varieties of ornamental fishes. Proper breeding, culture and marketing of these fishes could help to contribute to the export of the aquarium fishes in the international countries and gain foreign exchange. It will help the fisherwomen to earn a better mode of living and improve their financial status.

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Chapter- 5

Bioremediation of Heavy Metals by Microbial Process

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Keywords: Heavy metal; Bioremediation; Bioaccumulation; Toxicity; Oxidative stress

Abstract:

Heavy metal toxicity, persistence, bioaccumulation, and biomagnification make it a serious environmental problem. There are several natural and human-caused factors that can lead to environmental heavy metal pollution. The main natural sources of heavy metals are rock weathering and volcanic eruptions. However, burning fossil fuels and petrol, mining, incinerators for trash, industrial and agricultural activities, metal-bearing rocks, and so on are human sources of heavy metals. The most common heavy metal pollutants that are extremely dangerous include lead, zinc, copper, mercury, arsenic, chromium, nickel, and arsenic. Oxidative stress development is the fundamental chemical process of metal poisoning. Stress weakens the immune system, ruins tissues and organs, leads to birth abnormalities, and reduces the ability to procreate. One innovative and promising technique that can be used to remove and reduce heavy metals from water and contaminated soil is bioremediation. An important component of heavy metal bioremediation is microorganisms. Genetically modified organisms can be created by genetic engineering, and these organisms have the potential to produce fewer polycyclic hydrocarbons (PAHs). There are numerous methods by which metals and microbes interact, including biosorption, bioaccumulation, and bioleaching. To preserve lives and carry out legislation relevant to heavy metal conservation in the environment, it is imperative to investigate the origins of these metals and the potentially harmful impact they have on human health.

Introduction:

As the world's population rises, so do human requirements and actions, which lead to an enormous buildup of toxic waste from many sources that contaminate our environment. Some of

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the negative effects of industrialization, like pollution, rising carbon emissions, and resource depletion, pose a threat to human health and the health of every region in the world. A few of the drawbacks of industrialization are that it forces technological advancements and alters human civilizations in ways that are both social and economic. High concentrations of non-essential heavy metals and metalloids (lead, cadmium and arsenic) in soils and irrigation water are harmful to the environment, food safety, and the health of people and animals (Samal et al., 2017; Chakraborty et al., 2019; Witkowska et al., 2021; Roy et al., 2022; Rangamani et al., 2023;). Flavobacterium, *Pseudomonas, Bacillus, Arthrobacter, Corynebacterium, Methosinus, Rhodococcus, Mycobacterium, Stereum hirsutum, Nocardia*, *Methanogens, Aspergilus niger*, *Pleurotus ostreatus, Rhizopus arrhizus, Azotobacter*, *Alcaligenes, Phormidium valderium*, and *Ganoderma applantus* are a few of the microbes that help in the bioremediation of heavy metals (Rajak, 2017; Thakur et al., 2021; Bala et al., 2022; Rajalakshmi and Paari, 2023). The most effective microbial resources for use in bioremediation or bacterial-assisted phytoremediation strategies that may help improve plant growth (Ghosh et al., 2023) and yield in contaminated soils have not yet been thoroughly analyzed, even though several bacterial strains have been reported to be capable of remediating heavy metal-affected soils (Wang et al., 2022).

Table 1: Heavy Metal-Induced Diseases: Unraveling the Pathway of Exposure.

Heavy Metal	Disease(s)	Pathway of Exposure
Lead	Lead poisoning	Ingestion of lead-contaminated food, water, or paint; Inhalation of lead dust or fumes (e.g., from lead-based paints, certain occupations)
Mercury	Minamata disease	Consumption of mercury-contaminated fish and seafood; Inhalation of mercury vapours (e.g., from industrial processes, dental amalgams)
Cadmium	Itai-Itai disease	Ingestion of cadmium-contaminated food, water, or tobacco; Inhalation of cadmium dust or fumes (e.g., from industrial processes)
Arsenic	Arsenicosis	Ingestion of arsenic-contaminated water, food, or air; Exposure through occupational activities (e.g., mining, smelting)
Chromium	Lung cancer (Hexavalent Cr)	Inhalation of hexavalent chromium compounds in certain occupational settings (e.g., welding, chrome plating)
Nickel	Lung and nasal cancers	Inhalation of nickel compounds, occupational exposure (e.g., nickel refining, alloy production)
Copper	Wilson's disease	Genetic disorder affecting copper metabolism; excessive intake from water or food
Aluminum	Alzheimer's disease	Although controversial, some studies suggest a link between aluminum exposure and Alzheimer's disease; exposure through food, water, and certain products

Heavy metal toxicity:

Globally water pollution is considered as one of the major threats that impact human health, ecosystem, and sustainable development. All over the world, massive industrialization and rapid urbanization adversely affect the ponds, lakes, and rivers water quality parameters (Bhattacharya, 2015; Mondal et al., 2022; Madhu et al., 2022). Nowadays the situation has become more adverse as the industries frequently release the wastes which contain metallic contaminants into the ecosystem, exceeding the permissible limit. Fishes are more susceptible to heavy metal pollution as they are continuously exposed to these pollutants and its potential for bioaccumulation. For this reason, fish are considered as an ideal biological indicator of heavy metal induced toxicity. A possible mechanism for heavy metal-induced toxicity in aquatic organisms is the production of reactive oxygen species (ROS) as they are exposed to the water-borne toxicants (Velma et al., 2009).

Major toxicity effects of heavy metals in environment:

Chromium: Predominantly chromium is present in the workplace and in nature in two different valence state- 1st Cr^{6+} and 2nd Cr^{3+} Like many other metallic ions, chromium may be toxic and is non-biodegradable for this reason it remains in the ecosystem and only keep changing forms (Mallesh et al., 2015). In drinking water, the permissible limit of chromium is 50microgram/L (IS:10500:2012) (Lushchak, 2015) Consumption of high doses of chromium has been proven as lethal to animals and humans as Cr (VI) is highly carcinogenic (Benjamin and Kutty, 2019).

Lead (Pb): Generally, lead is present in a very low concentration although it induces a variety of toxic effects on fish which are exposed to it having toxic effects on its membrane structure (Eroglu et al.,2015) and causes hypocalcaemia (Rogers et al., 2003).

Cadmium: Cadmium is one of the known heavy metal toxicant which having a toxic effect on fish. It is a naturally occurring element but is also released into the environment through industrial activities, such as mining, smelting, and manufacturing. Biologically cadmium is a very reactive component and that is why it is capable of causing both acute and chronic poisoning (Liu et al., 2022).

Oxidative Stress and Reactive Oxygen Species:

In toxicology research, oxidative stress is an important area as it involves increased lipid peroxidation, alterations in antioxidant scavenger levels, changes in the antioxidant levels, which can be marked as the first step toward contamination (Alves et al., 2006). In fish tissues, heavy metal accumulation causes oxidative stress by the generation of reactive oxygen species (ROS) for example, hydrogen peroxide, hydroxyl particles and superoxide radicals. The generation of reactive oxygen species has been considered as a probable mechanism of heavy metal toxicity in aquatic organisms which are exposed to waterborne contaminants (Kim & Kang, 2017a). Activation of free radical occurs in the fish which are exposed to heavy metal compounds. These free radicals may alter many physiological and metabolic parameters. Farag had experimentally shown that due to chromium exposure lipid peroxidation in the tissues of Chinook salmon (*O. tshawytscha*) was activated and showed that higher concentration of chromium significantly affects fish health (Obasohan, 2007a). On the other hand, Ahmed has cited that Potassium dichromate causes oxidative stress in European eel's (*A. anguilla* L.) gills and kidneys (Ahmad et al., 2006). Hexavalent chromium induced genotoxicity and production of oxidative stress were confirmed in common carp (*C. carpio*) (Kumar et al., 2013a).

Metal-Microbes interaction:

Constant exposure to metals aids in the development of microorganisms' resistance to heavy metals, as previously discussed. It is also crucial to understand the several ways that microorganisms and heavy metals interact, including

Biosorption: The process of biosorption involves the interaction of metal ions with the cell surface's polysaccharides and proteins. microorganisms that are both gramme positive and gramme negative have peptidoglycan layers (Nanda et al., 2019a). Teichoic acid, alanine, glutamate, and meso-diaminopimelic acid are the main components of gram-positive bacteria, but gram-negative bacteria only have one peptidoglycan layer that contains phospholipids, glycoproteins, enzymes, and lipopolysaccharide. For the binding of metals, these molecules function as ligands. Teichoic acid-containing carboxyl groups and other acidic groups function as channels for the uptake of metals. Therefore, compared to gram negative bacteria, teichoic acid-containing bacteria absorb more metal ions. Nucleic acid, proteins, lipids, and carbohydrates combine to produce the complex cell wall of gram-positive bacteria, which also contains extra poly substances (EPS) (Ayangbenro & Babalola, 2017a).

Bioaccumulation: The transporter protein on the lipid bilayer drives this process, which allows the metal ions to pass through and reach intracellular regions. In bacteria, endocytosis, lipid permeation, carrier-mediated transport, and complex permeation are the ways in which heavy metals are collected. Studies using *Pseudomonas putida* 62BN for cadmium bioaccumulation by TEM have revealed cadmium accumulation in the periplasm and intracellular spaces (Pande et al., 2022a).

Genetic imprint that determines bacterial resistance to heavy metals:

When bacteria are exposed to heavy metals over time, the findings indicate that the bacteria develop resistance to the heavy metals, which include lead, zinc, copper, arsenic, chromium, nickel, cadmium, and mercury. Bacterial plasmids and chromosomes include metal resistance genes. Compared to plasmids, chromosomal genes are more complicated. The first metal resistance genes were found in bacterial plasmids. For instance, the bacterial plasmid PMOL28, which localizes the cnr operon, functions as a chromium, nickel, and cobalt genetic determinant. According to Nies and Cooksey, the cop operon is a copper-resistant gene found in Pseudomonas sp. Four proteins, including copA, copB, copC, and copD, are encoded by this cop operon. The cop protein gathers copper ions and creates spaces in the periplasm and outer membrane of the cell. Certain bacteria exhibit comparable functions for both chromosomal and plasmid genes. For instance, the ars operon in plasmids and the genetic determinant in *E. coli* and *Bacillus subtilis* are physically identical. The mechanism could be different, though, as chromosomes should have the genes for homeostasis, while plasmids should include the genes for resistance to heavy metals (Shahpiri & Mohammadzadeh, 2018a; Mergeay et al., 1985a).

Table 2: Heavy Metal-Microbe Interactions: Exploring Modes of Action.

Heavy Metal	Microbe Interaction and Mode of Action
Mercury	Methylating bacteria, such as Desulfovibrio spp., convert inorganic mercury to toxic methylmercury, which bioaccumulates in aquatic organisms.
Arsenic	Certain bacteria, e.g., Bacillus spp., can transform arsenate into less toxic arsenite or volatile arsine gas.
Cadmium	Pseudomonas species and other metal-resistant bacteria can accumulate and detoxify cadmium through metallothioneins and other cellular mechanisms.
Lead	Lead-resistant bacteria, such as Cupriavidus metallidurans, can sequester lead through intracellular and extracellular binding mechanisms.
Chromium	Some bacteria, including Pseudomonas and Bacillus species, can reduce toxic hexavalent chromium [Cr (VI)] to less toxic trivalent chromium [Cr (III)].
Copper	Copper-resistant bacteria like Cupriavidus necator may employ efflux pumps and metal-binding proteins to tolerate high copper concentrations.
Nickel	Nickel-resistant bacteria, for instance, Staphylococcus aureus, can tolerate high nickel levels through active efflux systems and metal-binding proteins.

Mechanism of bioremediation by microbes:

Bioremediation is a process that uses living organisms, typically microorganisms, to degrade or remove pollutants from contaminated environments. Microbes play a crucial role in bioremediation due to their ability to metabolize and break down various contaminants. The process involves various microbial activities and interactions that contribute to the degradation of different types of pollutants.

Table 3: Unveiling the Intricacies: Microbial Bioremediation Mechanisms and Pathways for Environmental Cleanup.

Process Step	Description/Pathway
Adhesion	Microbes adhere to the metal surface through biofilm formation. This involves the secretion of extracellular polymeric substances (EPS) by the microbes.
Electron Transfer	Microbes may transfer electrons to or from the metal surface, utilizing it as an electron acceptor or donor in metabolic processes. This can lead to corrosion or microbial metal reduction, depending on the specific microbe involved.
Biofilm Growth	The microbial biofilm on the metal surface continues to grow, providing protection and a conducive environment for microbial activity. This layer can consist of various microbial species, forming a complex community.
Metabolic Processes	Microbes engage in metabolic activities such as metal ion uptake, precipitation, or redox reactions. This can result in the alteration of metal speciation and its physical properties.

Metal Transformation	Microbes may induce transformations in the metal structure, such as the formation of metal oxides, sulfides, or other compounds. This alteration can influence the metal's stability and reactivity.
Corrosion or Protection	Depending on the microbial activities, corrosion of the metal may occur due to microbial metabolism or, conversely, the microbial biofilm may act as a protective barrier against environmental corrosion agents.
Nutrient Cycling	Microbes participate in nutrient cycling processes, utilizing and recycling nutrients present in the surrounding environment, which can indirectly affect the metal-microbe interaction.
Quorum Sensing	Microbial communication through quorum sensing may influence the behaviour and activities of the microbial community on the metal surface. This coordination can impact the overall metal-microbe interaction.
Biomineralization	Some microbes have the ability to induce the formation of mineral deposits on the metal surface, contributing to the overall stability or instability of the metal-microbe interface.
Detachment	Microbial detachment from the metal surface may occur, leading to the release of planktonic microbes into the surrounding environment. This can contribute to the spread of microbial colonization to new surfaces.

Conclusion:

This process of bioremediation for heavy metals by microorganisms is environment-friendly. As microbes grow fast, so this this process by microorganisms is also very fast. Microorganisms interact with heavy metals and develop resistance against heavy metals, and they help to find solutions for heavy metal pollution. More research for finding new strategies which can detoxify metal ions should be done by genetically engineered microorganisms (GEMs).

Authors' contribution

The original concept and design of the book chapter has been done by AKP and SHM. SHM did the original article drafting, review and editing.PH did the review and editing.

Conflict of interest

The authors declare that they have no conflict of interest.

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Chapter- 6

The Rise of Artificial Intelligence in Education: Current Trends and Future Prospects

Somnath Das*, Saeed Anowar and Biswarup Ghosh

Keywords: Artificial Intelligence, Educational Technology, Future Prospects, New Trends

Abstract:

Educational Excellence Elevated: Embrace AI for Tomorrow's Teaching Today!... underscores the importance of harnessing AI to enhance educational quality, stimulate innovation, and equip educators for future teaching advancements. The recent integration of AI in education has attracted significant attention due to its potential to transform traditional teaching and learning methods. This study explores the expanding role of AI in education, offering insights into the current trends and potential future outcomes. It examines how AI technologies are reshaping traditional teaching methods, providing personalized learning experiences, intelligent tutoring systems, automated grading, adaptive assessments, and more. The study analyzes the current state of AI integration in educational environments, identifying key trends and applications that enhance teaching and learning. It investigates the potential benefits and challenges of AI adoption in education and considers future possibilities for AI in shaping the educational landscape. Through a comprehensive literature review, the study synthesizes findings from scholarly articles, reports, and academic journals. It includes insights from expert interviews and case studies to provide a well-rounded view of the topic. Findings show that AI technologies like machine learning algorithms, natural language processing, and intelligent tutoring systems are increasingly being used to personalize learning experiences, automate administrative tasks, and offer real-time feedback to students. Despite AI's potential to improve educational outcomes, challenges such as data privacy, equity, and ethical considerations must be addressed for responsible implementation.

Introduction:

The article titled "Rise of Artificial Intelligence in Education: Current Trends and Future Prospects" provides a thorough exploration of how AI is reshaping educational settings. It evaluates the use of AI in online learning, open and distance education, and machine learning technologies, emphasizing AI's ability to deliver personalized, efficient, and widely accessible education. The article underscores prominent AI trends such as intelligent tutoring systems, virtual classrooms, and adaptive learning platforms that enhance the teaching and learning

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experience. It acknowledges AI's potential but also considers challenges and ethical concerns including data privacy, equity, and the changing role of human educators. The article suggests that AI's future impact on education will lead to more dynamic, tailored learning opportunities for students across the globe.

Objectives:

1. To analyze the current state of AI integration in educational settings.
2. To evaluate *how online learning, open and distance learning, and machine learning* technologies combine to provide personalized, accessible, and efficient education globally.
3. To identify the ***key trends*** and ***applications*** of AI in enhancing teaching and learning processes.
4. To explore the potential ***benefits*** and ***challenges*** associated with the adoption of AI in education.
5. To examine the ***future prospects*** of AI in ***shaping*** the future of education.

Methodology:

This study adopts a comprehensive literature review approach, synthesizing findings from a wide range of scholarly articles, reports, and academic journals. Additionally, it incorporates insights from expert interviews and case studies to provide a holistic understanding of the subject matter.

Current state of AI integration in educational settings:

The state of AI integration in education involves evaluating multiple components, such as the adoption rate, types of AI technologies utilized, challenges, and possible benefits. A study by Li and Zhou (2020) notes a gradual increase in AI integration within education, as institutions use AI for personalized learning, virtual tutoring, and educational analytics. The adoption is fueled by AI's potential to improve teaching efficiency and student learning outcomes (Zawacki-Richter et al., 2019; Malhotra et al., 2023; Mittal & Jora, 2023).

A survey by the Consortium for School Networking (CoSN) reports that 82% of U.S. educational institutions have implemented some AI technology, with the most common uses being intelligent tutoring systems and learning analytics platforms (CoSN, 2020). A report by Holstein and McLaren (2021) points out the growing use of AI tools such as chatbots and virtual assistants, which offer personalized support to students, answer questions, and simplify administrative tasks. Despite these advancements, obstacles such as data privacy concerns, equity issues in AI access, and the necessity of professional development for educators to integrate AI effectively into teaching still exist (De et al., 2019; Li and Zhou, 2020). Research suggests that AI's effectiveness in education is influenced by factors like content quality, AI algorithm design, and alignment with pedagogical goals (Zawacki-Richter et al., 2019). Though AI integration in education is progressing, challenges persist. Ongoing research, investment in infrastructure, and support for educators are crucial to fully leverage AI's potential to enhance teaching and learning experiences.

Key trends and applications of AI in enhancing teaching and learning processes:

AI is transforming the landscape of education by revolutionizing teaching and learning methodologies across multiple fronts. Prominent trends and applications encompass personalized learning, intelligent tutoring systems, AI-driven chatbots, and data analytics to inform instructional strategies.

1. Personalized Learning: AI facilitates personalized learning by customizing educational experiences to meet the unique needs of individual students, adapting content and pacing according to their performance and learning preferences. Adaptive learning systems such as DreamBox Learning and Knewton utilize AI algorithms to assess a student's understanding of the material continuously and dynamically adjust difficulty levels in real-time. *DreamBox*, for instance, demonstrated a 21% increase in math proficiency after 16 weeks of use in K-8 students. *Knewton*, meanwhile, reported 10-15% improvements in learning outcomes for higher education students compared to traditional methods. The benefits of personalized learning include increased engagement, improved outcomes, and data-driven insights for targeted support. Success stories from various schools and universities support these benefits, including findings from the Bill & Melinda Gates Foundation and research published in the Journal of Learning Analytics that show higher retention rates and better exam performance among students using adaptive learning systems. AI-driven personalized learning continues to demonstrate significant potential for enhancing teaching and learning processes.

2. Intelligent Tutoring Systems (ITS): Intelligent Tutoring Systems (ITS) harness AI to deliver personalized one-on-one tutoring experiences for students, offering immediate feedback and guidance to enhance their understanding of concepts. It’s features include adaptive learning paths based on students' learning styles and performance, immediate feedback during exercises, gamification elements to keep students engaged, and data-driven insights for educators. Carnegie Learning is a notable example of an AI-driven ITS for math education, offering personalized lessons, real-time feedback, and student progress tracking. Research has displayed that students applying AI-powered tutoring systems like Carnegie Learning demonstrate significant improvements in math performance, while educators report enhanced student engagement and learning outcomes with AI-based educational tools. As AI technology advances, ITS is expected to play an increasingly important role in enhancing education. According to a report by EdWeek Research Center, 83% of educators surveyed found that AI-based tools in education, including ITS, improved student engagement and learning outcomes.

3. AI-Powered Chatbots: AI-powered *chatbots* like Jill Watson at Georgia Institute of Technology have gained popularity in educational settings due to their ability to offer instant support and guidance to students. Jill Watson, employed in an online AI course by Professor Ashok Goel, is integrated into the course's online forum to answer questions about the class using natural language processing and machine learning algorithms. The *chatbot's* quick responses reduce wait times for students compared to traditional methods, and it alleviates the burden on teaching assistants by handling routine questions. Initially mistaken for a human teaching assistant, Jill Watson's acceptance among students improved as they recognized its efficiency and continuous learning capabilities. These *chatbots* enhance the student experience and free up instructors to focus on more complex tasks.

4. Data Analytics to Inform Instruction: In education, data analytics utilizes AI to collect, analyze, and interpret student data, aiming to enhance teaching and learning outcomes. Through the examination of performance metrics like grades, attendance, and engagement levels, AI can identify students at risk of academic challenges and facilitate timely interventions to support their progress. According to EdSurge, such predictive analysis has shown 80% accuracy in identifying at-risk students. Tailored instructional strategies can be developed using AI to address students' specific learning challenges, according to the National Education Policy Center's report on data-driven instruction. Additionally, AI-driven analytics enables teachers to offer personalized feedback and assessments, aiding students' progress, while continuous monitoring allows for real-time, data-informed decisions that improve teaching and learning. For instance, a study from the Journal of Educational Computing Research found that real-time AI monitoring of student progress enhances academic performance and engagement.

Online Learning, Open and Distance Learning, and Machine Learning Associated with AI:

AI in education is closely linked to online learning, open and distance learning, and machine learning. AI-driven online learning platforms employ machine learning algorithms to customize educational content and adjust to each student's requirements. Open and distance learning programs often utilize AI technologies to organize large educational resources and deliver individualized support to remote students. Machine learning enhances the quality and efficiency of these educational approaches by predicting students' needs, providing personalized content, and facilitating intelligent tutoring.

Online learning associated with AI: Refers to the integration of artificial intelligence technologies into online educational platforms to personalize learning experiences, provide automated feedback, and analyze student data to improve teaching methods. For instance, AI algorithms can adapt course materials based on individual learning styles and performance metrics (Tane et al., 2019).

Online Learning Platforms Leveraging AI: Online learning platforms harness artificial intelligence to deliver tailored learning experiences. For instance, platforms such as Coursera and Khan Academy employ AI algorithms to evaluate learner data and preferences, providing personalized recommendations and adaptive assessments (Liyanagunawardena et al., 2018). AI-powered chatbots, such as those used by *Duolingo* for language learning, provide instant feedback and assistance, enhancing the learning process (Dabbagh & Kitsantas, 2012). Through these personalized approaches, online learning becomes more engaging and effective for learners worldwide.

Open and Distance Learning associated with AI: Pertains to the application of artificial intelligence in the field of open and distance education. AI can enhance *ODL* by offering personalized learning paths, automated grading systems, and virtual tutoring support (Mishra, and Panda, 2020).

Open and Distance Learning Enhanced by AI: Open and distance learning (*ODL*) can reach remote or underserved populations with the help of AI technologies. For instance, the African Virtual University (*AVU*) employs AI to develop adaptive learning systems tailored to the needs of African students, improving access to quality education (Makulilo, 2015). Furthermore, programs like the Global Learning XPRIZE challenge encourage innovators to create AI-driven apps that help children in developing countries learn basic reading, writing, and arithmetic on their own (Kirschner & Wang, 2019). These initiatives showcase AI's potential to address educational disparities and empower learners in environments with limited resources.

Machine learning with AI: A branch of artificial intelligence, focuses on teaching computers to learn from data and enhance their performance without explicit programming. In the educational context, machine learning algorithms can facilitate the development of adaptive learning systems, forecast student outcomes, and evaluate educational data (T. M., 1997).

Machine Learning for Educational Enhancement: Machine learning algorithms assess educational data to improve teaching approaches and predict student outcomes. For instance, Carnegie Learning's Cognitive Tutor leverages machine learning to adaptively structure math instruction, offering students tailored support (Koedinger et al., 2012). The University of Michigan's ECoach platform employs predictive analytics to spot at-risk students and provide prompt interventions, thereby boosting retention rates (Bell et al., 2015). Furthermore, machine learning automates administrative duties such as grading and scheduling, giving educators more time to focus on individualized instruction (Kizilcec et al., 2017).

The adoption of AI in education has the potential to bring about significant benefits and challenges:

Potential Benefits:

1. Personalized Learning: Personalized learning harnesses AI to assess data on students' learning preferences, strengths, and areas for improvement, crafting tailored learning strategies. This customized method enables students to progress at their own speed and in alignment with their unique requirements. AI analyzes data such as students' previous performance, learning speed, and engagement with different topics to offer tailored learning experiences. For instance, platforms like DreamBox Learning utilize AI to customize math instruction according to individual student performance, enabling students to advance through the curriculum at their own pace. Similarly, adaptive learning platforms such as Knewton and Smart Sparrow provide personalized educational content based on real-time assessments of students' progress and learning preferences.

2. Automated Grading: AI can automate grading tasks, saving teachers time and allowing them to focus more on teaching and supporting students. Automated grading can also provide immediate feedback to students, helping them learn more effectively. Automated grading systems, such as those offered by Turnitin and Gradescope, use AI to provide feedback on written assignments and exams. These systems can evaluate essays, quizzes, and other assignments for grammatical errors, plagiarism, and even critical thinking, helping teachers manage large classes more efficiently. This immediate feedback can help students identify areas of improvement quickly and understand their mistakes, which can enhance the learning process.

3. Resource Optimization: I can help schools and educators optimize resource allocation, such as identifying students who may need extra support and providing targeted interventions. AI can assist in identifying students who need extra help or advanced challenges by analyzing performance data across multiple assignments and tests. For example, systems like Hobsons' Naviance leverage AI to guide students toward appropriate career paths and educational goals. AI can also help school administrators allocate resources more effectively by predicting future enrollment trends and identifying areas where additional support staff may be needed.

4. Intelligent Tutoring Systems: Intelligent Tutoring Systems, powered by AI, provide students with immediate support and feedback, assisting them in navigating complex concepts and fostering skill development. For instance, AI-driven tutoring platforms such as Carnegie Learning's *MATHia* and Century Tech deliver personalized tutoring sessions and practice exercises customized to each student's learning requirements. These systems offer detailed explanations, hints, and interactive feedback, empowering students to comprehensively grasp challenging subjects.

5. Improved Accessibility: AI enhances accessibility for students with disabilities by offering assistive technologies such as speech-to-text, text-to-speech, and language translation tools. These AI-driven tools support students with various needs, enabling them to engage more effectively with educational content and participate in learning experiences on an equal footing with their peers. AI can enhance accessibility for students with disabilities through tools such as text-to-speech software like Natural Reader and speech-to-text software like Dragon NaturallySpeaking. AI-powered language translation tools, such as Google's Interpreter mode, can help non-native English speakers understand and participate in classroom activities.

Potential Challenges:

1. Privacy Concerns: AI in education entails gathering and analyzing students' personal data, which raises concerns about data security, privacy breaches, and potential misuse of information. AI-powered educational platforms often accumulate large volumes of student data, such as learning progress, interactions, and assessments. This can lead to worries about the security of sensitive information and the possibility of data breaches, necessitating careful handling and robust security measures to protect students' data and privacy. For instance, in 2020, a data breach involving *ProctorU* exposed the personal information of students and testtakers. There is also the issue of third-party access to data, as AI platforms may share data with partners or advertisers, raising ethical concerns about consent and data misuse.

2. Bias and Fairness: AI systems have the capacity to adopt biases present in the data used for their training, potentially resulting in unfair treatment of students, particularly those from marginalized communities. When AI systems are trained on biased data, they may sustain and possibly exacerbate prevailing inequalities. For instance, facial recognition software has been found to struggle with accurately identifying individuals with darker skin tones, which can pose risks when used in educational settings for monitoring students. To mitigate bias and ensure fairness and equity for all students, continuous monitoring and evaluation of AI models are essential. This includes regular audits of AI algorithms and data sources, as well as implementing bias-correcting techniques. Involving diverse perspectives in the development and assessment of AI systems can also help address and prevent biases.

3. Dependence on Technology: Overreliance on AI and technology may lead to reduced human interaction in education, impacting students' social skills and emotional development. Excessive reliance on AI and technology in education can impact students' ability to develop critical social and communication skills. For instance, when students primarily interact with AI systems instead of teachers or peers, they may miss out on important opportunities for collaboration and interpersonal development.

4. Ethical and Legal Issues: The integration of AI in education prompts ethical and legal questions surrounding accountability, transparency, and informed consent.

Accountability: Educators and institutions must ensure that AI systems are fair, reliable, and beneficial to students. It's essential to establish clear lines of responsibility in case of errors or harm caused by AI tools.

Transparency: Institutions should be transparent about how AI systems make decisions, how data is collected and used, and the impact these systems have on students' educational experiences. This transparency helps build trust and enables stakeholders to understand the AI processes involved.

5. Informed Consent: Students and their guardians should be fully informed about the use of AI in educational settings, including how their data will be collected, analyzed, and used. Consent should be obtained prior to implementing AI-driven systems, ensuring respect for students' privacy and autonomy. AI integration in education raises ethical questions around informed consent, as students and parents may not fully understand how their data is being used. This can lead to concerns about transparency and accountability in AI systems. Legal issues may arise due to the lack of clear regulations surrounding AI in education, particularly regarding data privacy, intellectual property, and liability for AI-related decisions.

6. Digital Divide: The digital divide poses a notable obstacle in education, as some students lack access to technology and high-speed internet, exacerbating prevailing inequalities. This discrepancy can result in unequal educational outcomes, especially for students from low-income or rural backgrounds. Addressing the digital divide entails initiatives like equipping students with devices and internet access, along with training teachers to adeptly incorporate AI and technology into their teaching methodologies.

By addressing these challenges proactively, educational institutions can ensure that AI is used responsibly and effectively to enhance student learning while safeguarding privacy and promoting equity.

The future prospects of AI in shaping the future of education:

The future prospects of AI in shaping the future of education are promising, yet present both opportunities and challenges that require careful consideration and planning. Here is an analysis of this objective with supporting data and citations:

Prospects:

1. Enhanced Learning Experiences:

- AI has the potential to enrich learning experiences by increasing their interactivity and engagement levels. Virtual and augmented reality (VR/AR) technologies, fueled by AI, can provide students with immersive, visual experiences, aiding their understanding of intricate concepts effectively.
- AI-powered *chatbots* and virtual assistants can furnish students with instantaneous support, addressing their queries and aiding them with assignments and coursework in real-time.

2. Improved Assessment and Feedback:

- AI systems may evolve to offer more nuanced assessments of students' skills, including soft skills like creativity, collaboration, and critical thinking. These systems can track students' progress and offer personalized feedback to aid improvement.
- Advanced automated assessments could utilize AI to generate detailed insights into students' learning behaviors, guiding teachers in developing more effective instructional strategies.

3. Global Collaboration and Access:

- AI can enable global collaboration among students and educators, transcending geographical boundaries to create cross-cultural learning experiences.
- AI-driven language translation tools can help students from different language backgrounds participate in collaborative projects and access educational resources worldwide.

4. Adaptive Curriculum and Teaching Methods:

- AI can enable adaptive curriculum development, allowing educators to modify teaching materials and methods based on real-time data about students' performance and needs.

- As AI continues to advance, teachers may increasingly collaborate with AI systems to create personalized learning pathways for students.

5. Lifelong Learning and Reskilling:

- AI can support lifelong learning by providing personalized education and training opportunities throughout a person's life. This is particularly important in the context of rapid technological changes and shifting job markets.
- AI-powered platforms can help individuals identify skills gaps and offer targeted courses and resources to support continuous learning and career development.

Challenges and Considerations:

Ethical and Regulatory Frameworks: As AI shapes the future of education, establishing clear ethical and regulatory frameworks is essential to guide its use. Ensuring transparency, fairness, and accountability in AI systems is crucial. Policymakers, educators, and AI developers should work together to create standards for AI's role in education to safeguard students' rights and ensure equitable access.

Teacher Training and Adaptation: Preparing teachers with the essential skills and knowledge to seamlessly incorporate AI into their teaching is crucial. Professional development initiatives and resources will be pivotal in aiding teachers during this shift. It's vital to maintain a balance between AI utilization and traditional teaching approaches to uphold human connections within education.

Finding:

- ☑ [1]AI integration in education is increasing, with institutions utilizing AI for personalized learning, virtual tutoring, and educational analytics. AI technologies like intelligent tutoring systems and *chatbots* enhance teaching effectiveness, but challenges such as data privacy and access equity need to be addressed.
- ☑ [2]AI enhances teaching and learning processes through personalized learning, intelligent tutoring systems, AI-powered *chatbots*, and data analytics. These applications boost student engagement, improve learning outcomes, and provide data-driven insights for tailored support. However, ethical considerations and challenges remain in AI implementation.
- ☑ [3]AI-driven online, open, and distance learning provide personalized and adaptive educational experiences through machine learning algorithms. AI enhances educational resources, offering tailored content and virtual tutoring. These methods reach remote and underserved populations, predict student outcomes, and streamline administrative tasks, ultimately making quality education more accessible and effective for learners worldwide.
- ☑ [4]AI in education offers personalized learning, automated grading, resource optimization, intelligent tutoring, and improved accessibility. However, challenges include privacy concerns, potential bias, overreliance on technology, ethical and legal issues, and the digital divide. Proactive measures are essential to use AI responsibly and equitably in education.

☑ [5]AI's future prospects in education include enhanced learning experiences through *VR/AR*, advanced assessment and feedback, and global collaboration. It supports adaptive curriculums and lifelong learning opportunities. Challenges include ethical considerations, regulatory frameworks, and teacher training for effective AI integration while maintaining human connections.

Conclusion:

AI integration in education offers significant opportunities for personalized learning, intelligent tutoring, and adaptive educational experiences. These applications enhance teaching effectiveness and provide data-driven insights, while AI-driven online and distance learning improve access to education worldwide. However, challenges such as data privacy, potential bias, overreliance on technology, and the digital divide must be addressed. Ethical and legal considerations, alongside robust regulatory frameworks, are essential to guide AI use responsibly. Supporting teacher training and adaptation to AI tools will also be crucial. AI's future in education promises enriched learning experiences and lifelong learning balanced with thoughtful human-centered approaches.

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Chapter- 7

Unveiling the Potentials of *Withania somnifera* (L.) Dunal as a Precise Therapeutic Intervention Against Glioblastoma Multiforme

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Keywords: Glioblastoma Multiforme, *Withania somnifera*, phytotherapy, Withaferin A, Withanolides

Abstract:

Glioblastoma multiforme (GBM) is the most severe and fatal form of brain tumor, leading to a poor survival rate in patients and making a significant contribution to cancer-related deaths. The typical approaches to treating GBM involve surgical procedures followed by chemotherapy, targeting molecular pathways involving receptors like Epidermal Growth Factor Receptor (EGFR, EGFRvIII) and Vascular Endothelial Growth Factor Receptor (VEGFR) to modulate various cell signaling pathways. However, the effectiveness of current GBM treatments is notably constrained. *Withania somnifera* (WS) (L.) Dunal, commonly known as Ashwagandha, has a history spanning over 3,000 years in Ayurvedic and traditional medicine. This medicinal plant has diverse properties, encompassing anti-inflammatory, anticancer and antioxidant attributes. Recent advancements in the field of herbal and traditional medicines have explored its potential in managing deadly diseases like cancer. Ashwagandha or *W. somnifera*, mostly found in dry, sub-tropical regions of the world including India, is a well-known source of traditional and herbal medicines, and has many specific phytochemicals, viz. Withaferin A, Withanolide etc. This review discusses the potential of *W. somnifera*, supported by several research reports dealing with the extracts and phytochemicals from different parts of the plant, showing effectiveness against

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GBM in vitro and in vivo. Therefore, studying the effectiveness of *W. somnifera*- derived phytochemicals on specific therapeutic targets of GBM could unveil a new avenue in managing GBM. This review has exhaustively surveyed and analyzed several research reports from various literature databases on *W. somnifera*, its phytochemicals, and its leaf or root extracts as potential therapeutic interventions against GBM. It is evident that GBM management requires precise therapeutic intervention to achieve better overall survival rates in patients. *W. somnifera* holds promise in addressing the molecular targets associated with the disease, integrating precision medicine into phytotherapy. However, further research is imperative to establish these phytocompounds as nutritional supplements and to develop promising therapeutic strategies for combating GBM.

Introduction:

Glioblastoma multiforme (GBM) is considered the most aggressive and lethal type of brain tumor (Hanif et al., 2017). The reported 5-year patient survival has been consistently poor, varying to about 5% in the past three decades (Ledger et al., 1999; Youlden et al., 2012). There are 100,000 new instances of glioblastoma diagnosed annually worldwide. Despite having a low incidence rate of less than 6 per 100,000 people, glioblastoma accounts for 2.5% of all cancer-related fatalities and with the leading cause of mortality from cancer in those between the ages of 15 and 34 (Hanif et al., 2017). Managing recurrent cases of the illness has been challenging and unpredictable. Traditional chemotherapeutic agents have included drugs like temozolomide, lomustine, carboplatin, and carmustine in various dosages, with typical response rates less than 20%, 6-month progression-free survival around 15%, and overall survival typically less than 6 months, although outcomes across studies have shown variability (Wong et al., 1999; Batchelor et al., 2013).

Chemotherapeutic drugs frequently result in complications and increased malignancy with recurrent cases of GBM. Targeting these recurrent cases based on their molecular profiles has proven to be challenging, thus necessitating a personalized approach. Researchers have found that effectively targeting the tumor involves identifying the underlying cause of recurrence and detecting the signaling pathways involved. Over the years, an expanding array of phytochemicals has been employed due to their potential to target specific pathways and receptors, alongside their efficacy in penetrating the Blood-Brain Barrier (BBB). Indian traditional medicine has a notable history of employing different kinds of plants to cure a variety of diseases, and one such widely used plant in Ayurvedic studies is *Withania somnifera* (WS), commonly known as Ashwagandha or Winter Cherry (Andallu and Radhika, 2000). According to Ayurvedic medical tradition, the Rishi (sage) Punarvasu Atriya is credited with discovering the plant's therapeutic properties over 3,000 years ago (Tiwari et al., 2014). Ashwagandha possesses immunomodulatory, hemopoietic, anti-inflammatory, anticancer, anti-stress, and antioxidant potentials, also benefitting the endocrine, cardiovascular, and central nervous systems (Mishra et al., 2000). With over twenty-nine bioactive compounds found in different parts of the plant, mostly alkaloids, steroidal lactones, and saponins, preparations of *W. somnifera* have been discovered to have a therapeutic role in practically all CNS-related disorders, neurodegenerative diseases, neuropsychiatric diseases, and drug addiction (Kulkarni and Dhir, 2008). In combating prostate cancer, the modulation of antitumor immunity with the help of Ashwagandha is promising (Dubey et al., 2021). Withaferin A (an important withanolide of WS) has been shown to trigger triple-negative breast cancer cell-specific clinically relevant anticancer effects at certain pharmacological levels (Szarc et al., 2014). WS water extracts proved to be a potential candidate in differentiation-based therapy of human neuroblastomas by simultaneously inducing downregulation of MMP 2 & 9 and apoptosis (Kataria et al., 2013). The anticancer activity of Ashwagandha and its ability to target and suppress tumors inspired researchers to find its effect on GBM.

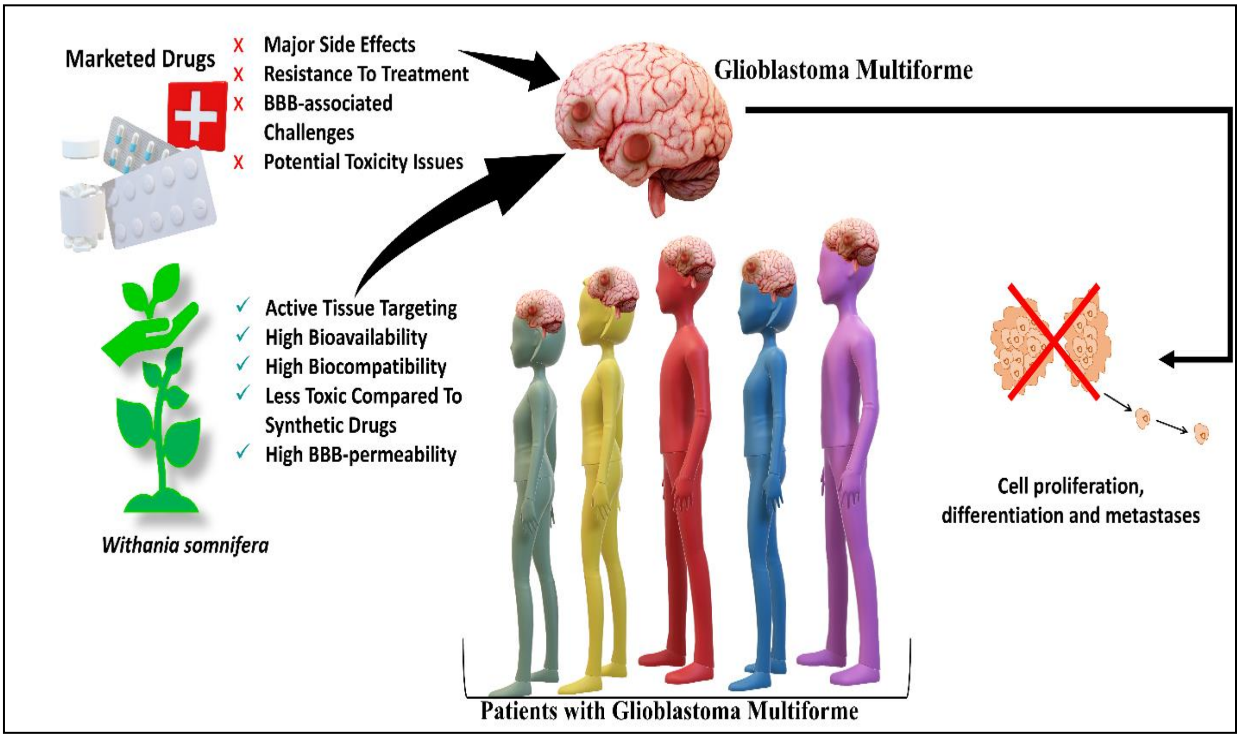

Figure 1. Graphical description of the study

Potential Targets for Glioblastoma Multiforme:

Glioblastoma Multiforme, the most malignant form of Glioma, poses a challenge in terms of complexity and management. The current treatment strategies mostly include surgical interventions followed by chemotherapy, along with the exploration of novel molecular targets such as EGFR, EGFRvIII, and VEGFR. Several potential targets for GBM are yet to be addressed. Typically, patients diagnosed with Glioblastoma undergo conventional treatment involving surgery wherever feasible, followed by field radiation combined with temozolomide chemotherapy up to six maintenance cycles (Weller et al., 2017; Stupp et al., 2005). No alternative treatment strategy has demonstrated an increase in overall survival for newly diagnosed patients, except for tumor-treating fields (Stupp et al., 2017). Although strictly limited in the newly diagnosed context, the methylation of the O6-methylguanine DNA methyltransferase (MGMT) promoter has been proven as a predictive biomarker for the benefit of treatment with temozolomide (Hegi et al., 2005; Hegi et al., 2019). The bulk of clinical trial strategies that aim at intrinsic targets of glioblastoma, address tyrosine kinase-mediated oncogenic signaling, cell cycle regulation, and vulnerability to apoptosis induction (Fig. 2). In this context, epidermal growth factor receptor (EGFR) is amplified by 40-50%, included with mutations at EGFRvIII in 50% of these, and without amplification by 10-20% can also be seen in GBM which stimulates proliferation, invasion, and apoptosis resistance (Brennan et al., 2014; Felsberg et al., 2017). By activating phosphatidylinositol-4,5-bisphosphate 3-kinase catalytic subunit alpha (PIK3CA) mutations or lack of tumor suppressor phosphatase and tensin homolog on chromosome ten (PTEN) function almost uniformly activates PI3K/AKT/mTOR pathway in IDH-wildtype GBM inducing metabolism, proliferation, and migration (Brennan et al., 2014). Activation of the Phosphorylated Protein Kinase B (AKT) pathway often observed in recurrent GBM occurs due to the higher levels of p-AKT phosphorylated by PDK-1 (3-phosphoinositide-dependent kinase-1). Fusion of fibroblast growth factor receptor (FGFR) with acidic coiled-coil (TACC) gene and sometimes by mutation causes proliferation of GBM (Singh et al., 2012; Di Stefano et al., 2015). Deletion or mutation in the p53 gene (35%) or neutralization of the p53 function by amplification of MDM2 or MDM4 gene (20%) has been reported in GBM (Brennan et al., 2014). In 90% of IDH-wild type GBM mutation in TERT promoter amplifies TERT transcription, which immortalizes tumor cells (Brennan et al., 2014; Killela et al., 2013; Sharma et al., 2022). Isocitrate dehydrogenase (IDH) mutations have also been observed where isoforms of IDH present in the peroxisomes and cytoplasm of glial cells exhibit increased oxidative damage and epigenetic alterations resulting in tumor growth (Horn et al., 2013). It has been revealed that altered proteasome activity may make cancer cells more vulnerable and has also been examined as a therapeutic target in recurrent GBM (Kong et al., 2019; Friday et al., 2012). Fusion in Neurotrophic tyrosine receptor kinases (NTRK) coding genes NTRK1/2/3 has been reported in 1-2% of GBM which stimulates proliferation (Ferguson et al., 2018). Up to 50% of epithelioid glioblastomas carry the uncommon BRAFV600E mutation, which induces proliferation. The proliferation-promoting MAP kinase/ERK signaling pathway is fed by a Raf family of kinase member BRAF (Korshunov et al., 2018). Overexpression of the Mesenchymal Epithelial Transition (MET) gene and infrequent amplification causes migration, invasion, and wound healing of GBM cells. It has been demonstrated that owing to homozygous CDKN2A/B deletion, RB1 gene mutations, or CDK4 or CDK6 amplification, most of the IDH-wild type glioblastomas have altered pRB cell cycle regulatory pathway (Brennan et al., 2014). Several other gene regulators were reported to be overexpressed. The Eukaryotic Initiation Factor 4A-3 (EIF4A3) is one such RNA binding protein, which is known to promote several oncogenes and their circularization, interact with miRNAs that regulate the cell cycle regulators, ultimately inducing the aggressive phenotype of GBM (Zhao et al., 2021). EIF4A3 promotes circular RNA Matrix metalloproteinase 9 (circMMP9), which in turn upregulates CDK4 and AURKA (Wang et al., 2020). EIF4A3 causes Temozolomide resistance by upregulation of NRAS (Wei et al., 2021). There are also a few potential microenvironmental targets in glioblastoma. Vascular endothelial growth factor (VEGF) forms new blood vessels where hypoxia triggers angiogenesis and becomes a potential factor for glioblastoma survival (Szabo et al., 2016; Plate et al., 1994). Cell surface molecule integrins and WNT proteins which integrate signals between cells and the extracellular matrix, play a crucial role in cellular activities like adhesion, invasion, migration, and angiogenesis determining the fate of the cell. World Health Organization (WHO) reports showed the increased localization of WNT signaling protein β-catenin and its complex with T-cell factor (TCF4) as higher in glioma and results in increased activation of transcription factors, thus promoting resistance to chemotherapeutic treatments (Sharma et al., 2022). In glioblastoma and associated vasculature, the involvement of specific subtypes of integrins has been established (Plate et al., 1994).

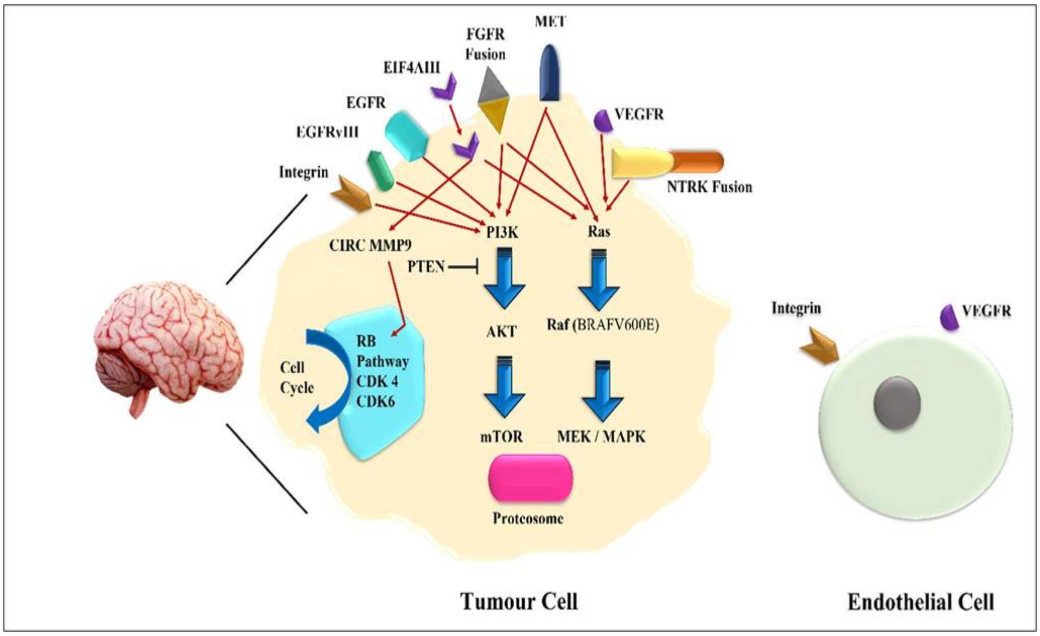

Figure 2. Several potential molecular targets in Glioblastoma Multiforme

Onco-medicinal Aspects of *Withania somnifera:*

WS is among the most prevalent Indian medicinal plants used in traditional medicine. Several bioactive compounds along with plant-specific phytochemicals, are present in various plant parts of WS, which are reported to exhibit potent activity against different types of cancers. Numerous studies have suggested that the use of WS's leaves, roots, seeds, and bark may derive benefits in cancer treatment (Kumar et al., 2017; Islam et al., 2014; Sinkar and Samarth, 2019; Li et al., 2016). Reports have confirmed the use of WS to be effective against breast cancer (Umair et al., 2019; Dar et al., 2019; Thaiparambil et al., 2011; Rah et al., 2016; Gowtham et al., 2022; Kim et al., 2015; Jawarneh and Talib, 2022; Li et al., 2015), alcoholic root extracts of WS have displayed inhibitory effects on the growth of the human breast cancer cell line (MCF7), hepatocellular carcinoma cell line (HepG2) consisting mutation in the TERT promoter, colon cancer cell line (CaCo2) with mutations in APC and β-catenin genes, and human non-small cell lung cancer cell line (A549) harboring KRAS (Kirsten rat sarcoma) mutant (Ahmed and El-Darier, 2022). Withaferin A (WA), a phytochemical present in different plant parts of WS, displays anticancer activity in human pancreatic cancer cell Panc-1 xenograft in nude mice, coupled with oxaliplatin, which causes reactive oxygen species-mediated inhibition of the PI3K/AKT pathway (Jawarneh and Talib, 2022). In pancreatic cancer cells, heat shock protein 90 (HSP90) is targeted by WA, which stimulates antiproliferative activity (Yu et al., 2010). Withaferin A in low doses has been found to be an effective inhibitor of HSP90, which resulted in growth arrest at the G2/M phase (Wang et al., 2019). Inhibition of HSP90 by WA was also observed in A20 B-cell lymphoma allograft in Balb/c female mice (McKenna et al., 2015). In Non-Small Cell Lung Cancer, WA inhibited cancer stem cell development by impacting numerous targets of the mammalian Target of Rapamycin (mTOR)/ Signal Transducer and Activator of Transcription 3 (STAT3) pathways (Hsu et al., 2019). In the development of human prostate cancer, the alcoholic leaf extracts of WS targeted interleukin-8 (IL-8) and cyclooxygenase-2 (COX-2) in the PC-3 prostate cancer cell line. Chronic inflammation, enhanced angiogenesis, proliferation, migration, and apoptosis inhibition occur in conjunction with overexpression of IL-8 and COX-2. Moreover, the disease's transition from an androgen-dependent to an androgen-independent state is promoted by their elevated circulating levels (Setty et al., 2017). Withaferin A has been reported to induce apoptosis and inhibition of the proteasome system in nude mice PC-3 prostate cancer xenograft (Srinivasan et al., 2007; Yang et al., 2007). By inhibiting the expression of the RET (REarranged during Transfection) gene, WA is a prospective inhibitor of medullary thyroid carcinomas (MTC) cell line DRO-81-1 xenograft in nude mice (Samadi et al., 2010). On the other hand, WA induced p53-dependent apoptosis in human cervical cancer cell CaSki xenograft in nude mice by suppressing HPV oncogenes and upregulating tumor suppressor proteins (Munagala et al., 2011). Aqueous extracts of WS root are highly cytotoxic to human malignant melanoma A375 cells (Halder et al., 2015). Recent evidence suggests that WA suppresses cell growth of human myeloma cells U266B1 and IM-9 by causing intrinsic apoptosis mediated by the induction of the reactive oxygen species (ROS) pathway (Li et al., 2022). Furthermore, it is reported that Eukaryotic Translation Initiation Factor 2A (EIF2A)-dependent inhibition of translation was observed in neurogenic locus notch homolog protein 1 (NOTCH1) mutated T-cell acute lymphoblastic leukemia (T-ALL) in xenograft NRG mice (Sanchez-Martin et al., 2017). By targeting putative cancer stem cells, WA alone or in combination with cisplatin inhibited the growth and spread of ovarian cancer in A2780 xenograft in nude mice (Kakar et al., 2014). By inhibiting AKT and c-MET activation, WA also promotes apoptosis in uveal melanoma cell 92-1 xenograft in SCID mice (Samadi et al., 2021).

Among the numerous withanolides present in the plant, Withaferin A, Withanolide A and Withanone have proved evidence for affinity towards GBM and other types of tumors. These steroidal lactones have been extensively studied for their Absorption, Distribution, Metabolism, and Excretion (ADME) properties to evaluate their antagonistic activities. Structurally, Withanone is an epoxy compound with oxygen atoms at positions C6 and C7, having hydroxyl groups at C5 and C17. In contrast, Withaferin A is an epoxy compound with oxygen atoms at C5 and C6 positions, accompanied by hydroxyl groups at C4 and C27. Early studies have shown the superiority of Withaferin A in inducing apoptosis in cancer cells at concentrations $<0.5 \mu g/mL$ (Vaishnavi et al., 2012). Extraction of Withanolides has enabled researchers to identify pathways and targets in the management of tumor cells. With the presence of structurally different phytochemicals in WS, it can address the tumor-inducing molecular targets in different types of cancer (Fig. 4).

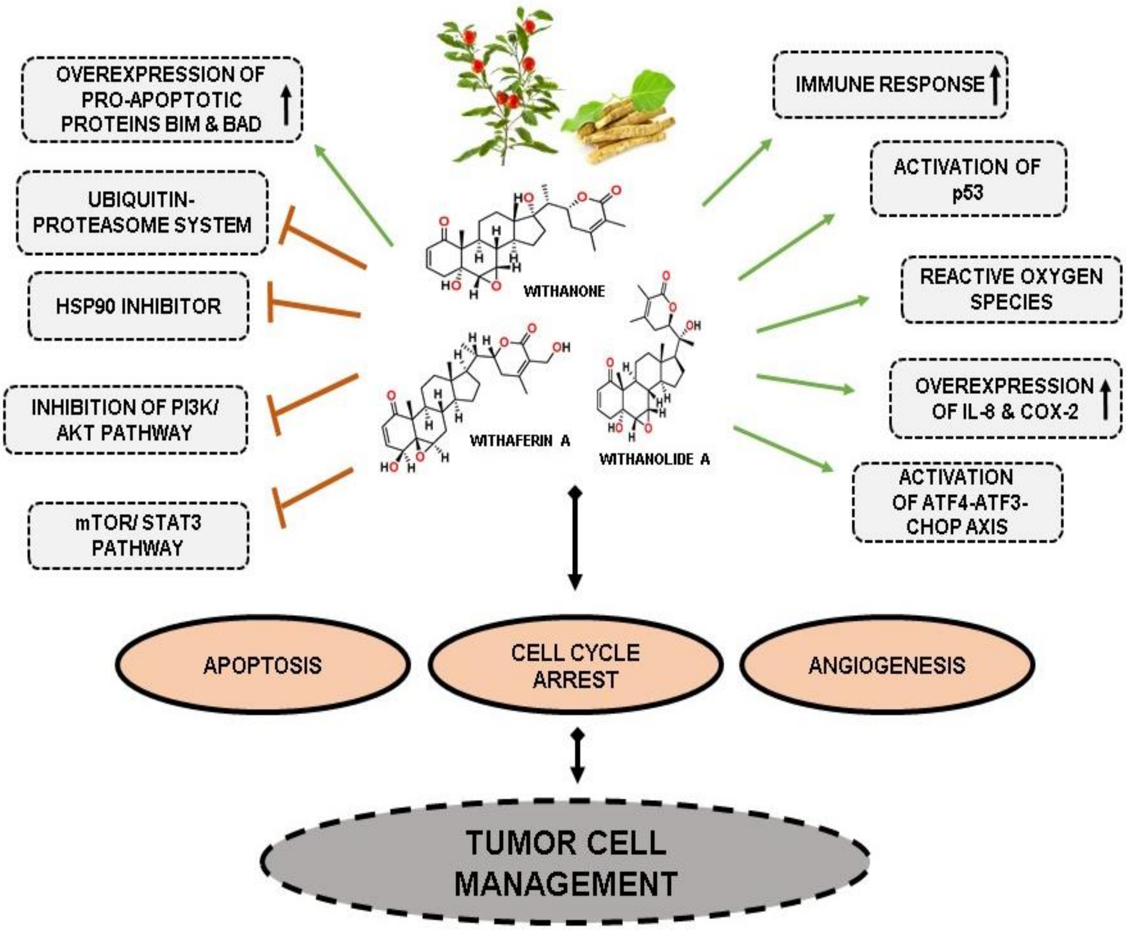

Figure 3. Several potential molecular targets of WS phytochemicals in the management of tumor cells

Phytochemical Profile of *Withania somnifera:*

Withania somnifera and its phytochemicals have been found effective in glioblastoma management (Kataria et al., 2016; Shah et al., 2009; Tang et al., 2020; Chang et al., 2016; Garg et al., 2018). An abundant number of phytochemicals have been found in the WS plant with a countable one specific to the *Withania* sp. While looking for a therapeutic cure for GBM, the effect of *Withania* sp.-specific phytochemicals existing in WS (Table 1) has been considered.

Table 1: Phytochemical profiling of different parts of WS.

Plant Part	Phytochemical Name	Reference	Plant Part	Phytochemical Name	Reference

Leaf	Withanolide Q	(Mohanraj et al., 2018)		Withaferin A	(Mohanraj et al., 2018; Khajuria et al., 2004; Mirjalili et al., 2009; Doma et al., 2012; Nakajima et al., 2011; Ali and Meitei, 2012)
	Withanolide R	(Mohanraj et al., 2018)		Withanolide E	(Mohanraj et al., 2018)
	Withanolide M	(Mohanraj et al., 2018)		Withasomnine	(Mohanraj et al., 2018)
	Withanolide D	(Mohanraj et al., 2018; Mondal et al., 2012)		Withanolide G	(Mohanraj et al., 2018)
	Withaferin A	(Mohanraj et al., 2018; Khajuria et al., 2004; Misra et al., 2005; Pramanick et al., 2008; Tong et al., 2011; Jayaprakasam et al., 2002; Mirjalili et al., 2009; Xu et al., 2011; Yoneyama et al., 2015)		Withanolide P	(Mohanraj et al., 2018)
	Withanolide E	(Mohanraj et al., 2018)		Withanone	(Mohanraj et al., 2018; Khajuria et al., 2004)
	Withasomnine	(Mohanraj et al., 2018)		Withanolide S	(Mohanraj et al., 2018)
	Withanolide G	(Mohanraj et al., 2018)		Withanolide C	(Mohanraj et al., 2018)
	Withanolide O	(Mohanraj et al., 2018)		Withanolide L	(Mohanraj et al., 2018)
	Withanolide P	(Mohanraj et al., 2018)		Withanolide J	(Mohanraj et al., 2018)
	27-Deoxywithaferin A	(Mohanraj et al., 2018)		Withanolide A	(Mohanraj et al., 2018; Khajuria et al., 2004; Soman et al., 2012; Doma et al., 2012; Zhao et al., 2002; Tohda et al., 2005; Kour et al., 2009; Nagella and Murthy, 2011; Soman et al., 2013; Devi et al., 1996)
	Withanolide N	(Mohanraj et al., 2018)		Withanoside XI	(Mohanraj et al., 2018; Zhao et al., 2002)
	Withanone	(Mohanraj et al., 2018; Khajuria et al., 2004; Misra et al., 2005;		WithanosideVIII	(Mohanraj et al., 2018; Zhao et al., 2002)

		Tong et al., 2011; Siddique et al., 2014)			
	17alpha-hydroxywithanolide D	(Mohanraj et al., 2018)		Withanoside X	(Mohanraj et al., 2018; Zhao et al., 2002)
	Withanolide S	(Mohanraj et al., 2018)		Ashwagandhanolide	(Mohanraj et al., 2018; Subbaraju et al., 2006)
	Withanolide C	(Mohanraj et al., 2018)		(-)-Anaferine	(Mohanraj et al., 2018)
	Withanolide L	(Mohanraj et al., 2018)		(2R)-2-[(1S)-1-[(8R,9S,10R,13S,14R,17S)-14,17-dihydroxy-10,13-dimethyl-1-oxo-4,7,8,9,11,12,15,16-octahydrocyclopenta[a]phenanthren-17-yl]-1-hydroxyethyl]-4,5-dimethyl-2,3-dihydropyran-6-one	(Mohanraj et al., 2018)
	Withanolide H	(Mohanraj et al., 2018)		Sitoindoside IX	(Garg et al., 2018)
	Withanolide I	(Mohanraj et al., 2018)		Anahygrine	(Garg et al., 2018)
	Withanolide K	(Mohanraj et al., 2018)		4-Hydroxy-1,26-dioxo-5,6:22,26-diepoxyergosta-2,24-dien-27-yl 6-o-hexadecanoylhexopyranoside	(Mohanraj et al., 2018)
	Withanolide J	(Mohanraj et al., 2018)		Coagulin Q	(Mohanraj et al., 2018; (Zhao et al., 2002)
	Withanolide A	(Mohanraj et al., 2018; Khajuria et al., 2004; Misra et al., 2005; Pramanick et al., 2008; Soman et al., 2012; Doma et al., 2012)		Withanoside IV	(Mohanraj et al., 2018; Tohda et al., 2005)
	Withanoside X	(Mohanraj et al., 2018; Tong et al., 2011)		Withanoside VI	(Mohanraj et al., 2018; Tohda et al., 2005)
	Withanolide B	(Mohanraj et al., 2018; Khajuria et al., 2004; Pramanick et al., 2008)		Withanolide B	(Mohanraj et al., 2018; Khajuria et al., 2004)
	(2R)-2-[(1S)-1-[(8R,9S,10R,13S,14R,17S)-14,17-dihydroxy-10,13-dimethyl-1-oxo-4,7,8,9,11,12,15,16-octahydrocyclopenta[a]phenanthren-17-yl]-1-hydroxyethyl]-4,5-dimethyl-2,3-dihydropyran-6-one	(Mohanraj et al., 2018)	**Seed**	Withaferin A	(Mohanraj et al., 2018)
	Sitoindoside IX	(Mohanraj et al., 2018; Jayaprakasam et al., 2003)		Anahygrine	(Mohanraj et al., 2018)

	Physagulin-d	(Mohanraj et al., 2018; Jayaprakasam et al., 2003)	**Stem**	Withaferin A	(Mohanraj et al., 2018; Khajuria et al., 2004; Mirjalili et al., 2009)
	Viscosalactone B	(Mohanraj et al., 2018; Jayaprakasam et al., 2003)		Withanolide B	(Mohanraj et al., 2018; Khajuria et al., 2004)
	Withanoside IV	(Mohanraj et al., 2018; Jayaprakasam et al., 2003)		Withanolide A	(Mohanraj et al., 2018; Khajuria et al., 2004)
Root	Withasomidienone	(Mohanraj et al., 2018)		Withanone	(Mohanraj et al., 2018; Khajuria et al., 2004)
	Withanolide M	(Mohanraj et al., 2018)			
	Withanolide D	(Mohanraj et al., 2018; Zhao et al., 2002)			

Pharmacological Effects of *Withania somnifera* on GBM Cell Behavior:

Effect of *Withania somnifera* on Proliferation and Migration of GBM cells:

Alcoholic leaf extracts of WS, Withaferin-A, Withanone, and Withanolide-A have demonstrated the ability to inhibit the growth or proliferation of glioma cells in a dose-dependent manner established in mice and human cell lines. Under moderate dosage administration, the growths of both human and mice cells were found to be severely arrested at S and G2/M phase by all four treatments with maximum effect within 48 to 72 hours. Strong reduction in the migration of mice glioma cells and human glioma cells were found to be more sensitive than mice (Shah et al., 2009). Withaferin-A also has the property to arrest cell growth at the G2/M phase in the human GBM cell line in low doses between 12 to 48 hours (Tang et al., 2020). Withaferin-A and AshwaMAX (a root extract with 4.3% w/w Withaferin-A content) inhibited the formation of neurosphere even in patient-derived glioblastoma cell lines while being treated in a dose-dependent manner within 24 hours of treatment. They also exhibited anticancer potentials in decreasing cell viability by almost 4-folds to a fewer than 20% ± 10 viable glioblastoma cells. The same study displayed the effect of AshwaMAX on nude mice with intracranial xenografts of GBM. Three types of GBM cells were used for xenografting, viz. U87-MG, GBM2, and GBM39, wherein GBM2 and GBM39 were patient-derived cell lines. The growth rate of tumor stabilized within 25 to 28 days of implantation, and subsequently 40 mg/kg/day AshwaMAX was delivered orally on every other day. All mice with U87-MG implantations experienced huge weight loss and therefore had to be sacrificed immediately after a month of surgical implantations. However, the GBM39 xenograft mice survived a month longer. In these cases, the growth of GBM cells were observed to be inhibited to some extent, nonetheless their migration could not be halted. For GBM2 xenograft mice, the tumors began to regress rapidly within one week of initiation of treatment and almost disappeared in one month. Surprisingly, after one-month, GBM reappeared due to resistance or migration of cells and76% of the GBM2 xenograft mice survived 7 months following implantation (Chang et al., 2016).

ASH-WEX (a leaf extract containing withanolides with Withaferin A as its major constituent in distilled water) has been found to be effective against C6 rat glioma intracranial allograft in Wistar strain male albino rat. Such rats with C6 intracranial allograft were administered with ASH-WEX equivalent to 140 mg/kg/day for consecutive 21 days. Reduced activity of MMP2 and MMP9 activities were however found following ASH-WEX treatment (Kataria et al., 2016), which further indicated the inhibition of metastasis of respective cancer cells.

Effect of *Withania somnifera* on GBM Cell Differentiation:

Low dosages of alcoholic leaf extracts of WS, Withaferin-A, Withanone, and Withanolide-A led to morphological alterations in cells that ranged from polygonal structure with a small number of cytoplasmic processes to spindle form with lengthy cytoplasmic processes, resembling those generally seen in differentiated astrocytic cells (Shah et al., 2009). Aqueous leaf extracts of WS and Withanone induced differentiation in rat glioblastoma cells at low doses (Shah et al., 2015). Cucurbitacin (*Helicteres angustifolia*) - Withanone combined application at low doses caused differentiation in rat glioma cells (Garg et al., 2018) (Table 2).

Effect of *Withania somnifera* on Apoptosis of GBM Cells:

High doses of alcoholic leaf extracts of WS, WA, Withanone, and Withanolide - A have the property to induce apoptosis in both mice and human glioma cells (Shah et al., 2009). WA has been shown to display apoptotic activity on GBM cells. Following 6 hours of WA treatment, the expression of the pro-apoptotic proteins, Bim and Bad, were dramatically elevated; expression of the anti-apoptotic proteins BclxL and Bcl2 were marginally altered, along with the pro-apoptotic proteins, Bak and Bax, further indicating that the intrinsic apoptotic pathways might have initiated by the main regulators, Bim and Bad. Silencing Bim and Bad expressions alternately enhanced the viability of WA-treated GBM cell lines, thus validating the role of WA in the suppression of GBM cells (Tang et al., 2020) (Table 2).

Table 2: Cellular reactions of glioblastoma cells in response to *Withania somnifera* treatment.

Cell line	Bioactive Compound (IC50 value)	Effect	Reference
C6 (rat glioma)	Alcoholic leaf extract (low dose)	Differentiation	(Shah et al., 2009)
	Alcoholic leaf extract (5 µg/mL)	Growth inhibition	(Shah et al., 2009)
	Alcoholic leaf extract (high dose)	Apoptosis	(Shah et al., 2009)
C6 (rat glioma)	Withaferin-A (low dose)	Differentiation	(Shah et al., 2009)
	Withaferin-A (0.2 µmol/L)	Growth inhibition	(Shah et al., 2009)
	Withaferin-A (high dose)	Apoptosis	(Shah et al., 2009)
	Withanone (low dose)	Differentiation	(Shah et al., 2009)
	Withanone (40 µg/mL)	Growth inhibition	(Shah et al., 2009)
	Withanone (high dose)	Apoptosis	(Shah et al., 2009)
	Withanolide-A (low dose)	Differentiation	(Shah et al., 2009)
	Withanolide-A (35 µg/mL)	Growth inhibition	(Shah et al., 2009)
	Withanolide-A (high dose)	Apoptosis	(Shah et al., 2009)

	Cucurbitacin (Helicteres angustifolia) (5 nmol/L) Withanone (2.5 µmol/L)	Differentiation	(Tang et al., 2020)
YKG1 (human glioma)	Alcoholic leaf extract (low dose)	Differentiation	(Shah et al., 2009)
	Alcoholic leaf extract (2.5µg/mL)	Growth inhibition	(Shah et al., 2009)
	Alcoholic leaf extract (high dose)	Apoptosis	(Shah et al., 2009)
	Withaferin-A (low dose)	Differentiation	(Shah et al., 2009)
	Withaferin-A (0.1 µmol/L)	Growth inhibition	(Shah et al., 2009)
	Withaferin-A (high dose)	Apoptosis	(Shah et al., 2009)
	Withanone (low dose)	Differentiation	(Shah et al., 2009)
	Withanone (30 µg/mL)	Growth inhibition	(Shah et al., 2009)
	Withanone (high dose)	Apoptosis	(Shah et al., 2009)
	Withanolide-A (low dose)	Differentiation	(Shah et al., 2009)
	Withanolide-A (20 µg/mL)	Growth inhibition	(Shah et al., 2009)
	Withanolide-A (high dose)	Apoptosis	(Shah et al., 2009)
	Withaferin-A (0.01 µmol/L) + Withanone (5 µg)	Best Differentiation	(Shah et al., 2009)
U87	Withaferin-A (4.61 µmol/L)	Growth inhibition	(Shah et al., 2009)
	Withaferin-A (10 µmol/L)	Apoptosis	(Tang et al., 2020)
U87-MG	Withaferin-A (0.31 µmol/L)	Growth inhibition	(Garg et al., 2018)
	AshwaMAX (1.40 µmol/L)		
U251	Withaferin-A (1.37 µmol/L)	Growth inhibition	(Tang et al., 2020)
	Withaferin-A (10 µmol/L)	Apoptosis	(Tang et al., 2020)
HA1800	Withaferin-A (9.13 µmol/L)	Growth inhibition	(Tang et al., 2020)
GBM2 (Patient Derived) (Human parietal-cortical glioblastoma cells)	Withaferin-A (0.28 µmol/L)	Growth inhibition	(Chang et al., 2016)
	AshwaMAX (root extract containing 4.3% w/w Withaferin-A) (0.19 µmol/L)	Growth inhibition	(Chang et al., 2016)
GBM39 (Patient Derived) (Human parietal-cortical glioblastoma cells)	Withaferin-A (0.25 µmol/L)	Growth inhibition	(Chang et al., 2016)
	AshwaMAX (root extract containing 4.3% w/w Withaferin-A) (0.22 µmol/L)	Growth inhibition	(Chang et al., 2016)

Therefore, Ashwagandha is a plant that has been well-researched and studied against GBM. It not only provides a promising scope for generic treatment of GBM but also opens an avenue for a precise or personalized line of treatment by targeting specific proteins whose overexpression leads to GBM progression.

Effect of *Withania somnifera* on Tumor Suppression Pathways Associated with GBM:

The p53 tumor suppressor pathway is activated by the alcoholic leaf extracts of WS and Withanone (i-Factor), which results in the selective death of cancer cells (Shah et al., 2009; Widodo et al., 2007; Widodo et al., 2008). Treatment with WS greatly reduced the expression of cytokines that are pro-inflammatory such as Interleukin (IL)-1β, IL-6, chemokine IL-8, STAT-2, and Heat shock protein, HSP-70. On the other hand, reciprocal induction was observed for cyclin D and cyclin C, p38MAPK, caspase 6, and PI3K. Treatment with WS dramatically changed the JAK-STAT pathway, which controls MAP kinase signaling as well as the apoptotic process

(Shah et al., 2009; Aalinkeel et al., 2010). Furthermore, by modulating the p21-Bad pathway, Withaferin-A caused apoptosis in human GBM cell lines which is independent of p53. In addition, ATF4, XBP1, and CHOP were upregulated by WA which induced p21 expression. Therefore, WS and its phytochemicals can actually modulate several signaling pathways in order to induce apoptosis in human GBM cells as given in Figure 4 (Tang et al., 2020).

Discussion:

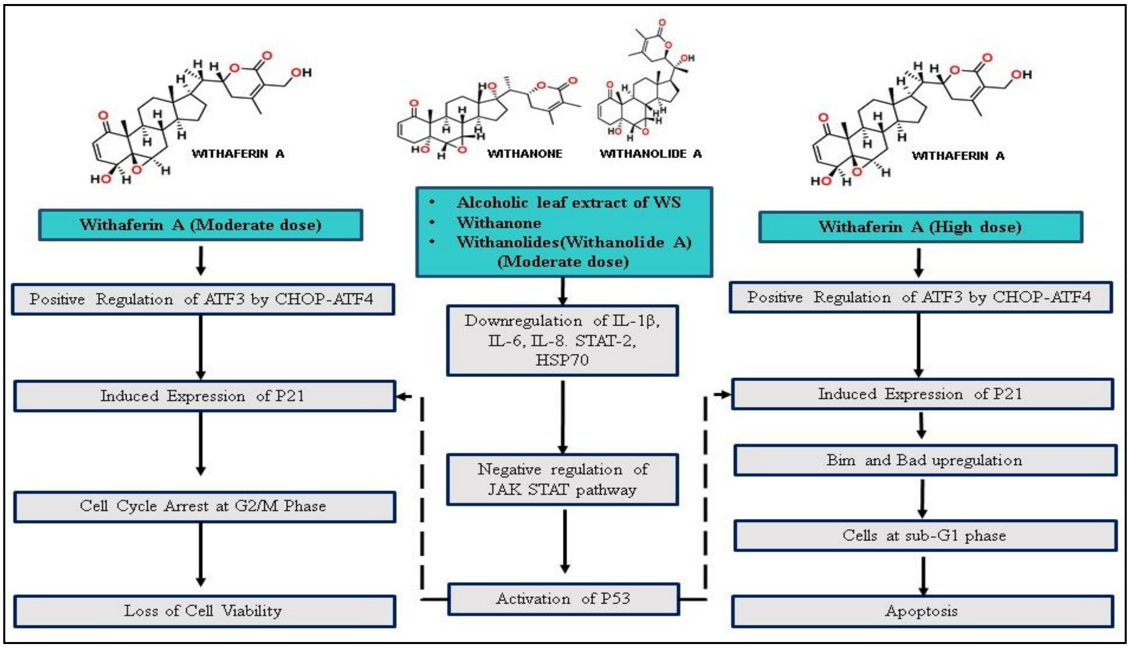

Figure 4. Mechanism of action of Withania somnifera specific phytochemicals in Glioblastoma Multiforme Management

Glioblastoma multiforme is regarded as the worst form of Glioblastoma with an exceptionally low survival rate with existing therapies indicating limited effectiveness for long-term patient survival. Due to the variety of molecular alterations in GBM cases, drug-based treatment has a significant challenge as no single therapeutic medicine can target GBM (Madhu et al., 2023). The presence of both inter-tumor and intra-tumor heterogeneity in GBM cases poses difficulties for diagnosis and therapy. Phytochemicals, being an integral part of our regular diet, hold great potential in disease management if used wisely. There have been instances of several Indian medicinal plants which have plant-specific phytochemicals, viz., Ashwagandha, cinnamon, black pepper, turmeric etc. The molecular targets that are now being aimed at in clinical trials with drugs may also be focused on by phytochemicals from WS. Furthermore, phytochemical therapy has the potential to reduce and alleviate adverse side effects of anticancer drugs. WS and its phytochemicals have been found effective against a broad range of cancers like skin carcinoma (Kumar et al., 2017; Bhattacharjee, 2020; Sinkar and Samarth, 2019; Li et al., 2016), breast cancer (Umair et al., 2019; Dar et al., 2019; Thaiparambil et al., 2011; Sarkar et al., 2022; Rah et al., 2016; Gowtham et al., 2022; Kim et al., 2014; Jawarneh et al., 2022; Li et al., 2015), hepatocellular carcinoma, colon cancer, non-small cell lung cancer (Ahmed et al., 2022; Madhu et al., 2022; Hsu et al., 2019), pancreatic cancer (Li et al., 2015; Yu et al., 2010), lymphoma (McKenna et al., 2015), prostate cancer (Setty et al., 2017; Srinivasan et al., 2007; Sanyal et al., 2018; Yang et al., 2007), thyroid carcinoma (Samadi et al., 2010) ovarian cancer (Kakar et al., 2014), melanoma (Halder et al., 2015) myeloma (Li et al., 2022), leukemia (Sanchez-Martin et al., 2017), and glioblastoma (Kataria et al., 2016; Shah et al., 2009; Tang et al., 2020; Chang et al., 2016; Garg et al., 2018) *in-vitro* and *in-vivo*. Few of the cancer types share some common pathways i.e., the JAK-STAT signaling study in prostate cancer cells. Presently, several reports suggest that abnormal JAK/STAT signaling plays a key role in glioma genesis and resistance to treatment (Aakinkeel et al., 2010; Ou et al., 2021). Negative regulation of the JAK-STAT pathway in turn stimulates the p53 pathway. Since a major cause of cancer is inactivation of p53, a mechanism of action of WS and its phytochemicals in GBM management is highly focused on the activation of p53 and p21. Alcoholic leaf extracts of WS, Withanone, and Withanolides force negative regulation of the JAK-STAT pathway which in turn stimulates activation of p53 followed by induced p21 expression resulting in growth inhibition of GBM cells (Shah et al., 2009). Withaferin A induces expression of p21 independent of p53, by positive regulation of ATF3 by CHOP-ATF4 (Tang et al., 2020). The activation of ATF4-ATF3-CHOP axis is important for the WA based therapy involving inhibition of cell cycle and apoptosis at the G2/M level (Kumar et al., 2023). The WA in low doses cause differentiation, in moderate doses they cause growth inhibition, and in high doses, they induce cell apoptosis by upregulating pro-apoptotic proteins Bim and Bad (Fig. 4). Though the *in-vivo* model depicted an increase in survival time, it also displayed formation of resistant sublines of GBM and migration towards microenvironments where WS root extracts were not effective (Chang et al., 2016). While evaluating the capability of WS phytochemicals in targeting signaling pathways, the structural advantages of steroidal lactones have paved the way for their affinity towards the target. Molecular docking, ADMET (Absorption, Distribution, Metabolism, Excretion, and Toxicity), and molecular dynamics studies indicate stronger affinity and inhibition of the regulating pathways in Glioblastoma stem cells (Dhami et al., 2017; Swati et al., 2023; Arsalan et al., 2023; Lee et al., 2022). The utilization of WS's phytocompounds presents an opportunity for the development of targeted medications in the fight against GBM. Recent research has also paved the way for fractionalization of many novel glycoside compounds from WS, providing experimental evidence by testing its anti-angiogenic properties against various tumors such as Hepatocellular carcinoma (Lee et al., 2022). Though there have been limited studies on the high-dosage side effects of Withanolides, few reports have suggested the possibility of liver damage in human patients occasionally with increased and regular dosages of WS extracts, with Withanone being the source of DNA damage. Although, cases showed quick recovery with drug withdrawal (Malik et al., 2013; Siddiqui et al., 2021). Persistent progress and discoveries in precision medicine, particularly in the realm of GBM treatments, it is essential to explore the WS-specific extracts domain. Extending the scope of research can enhance the prognosis and overall condition of GBM patients. The scientific community's continued investigation and the potential breakthroughs offered by precision medicine hold great promise for revolutionizing GBM treatment (Iyer et al., 2023).

Conclusion:

This study provides a complete insight on the use of Withanolides as a potential and unexplored approach for the treatment of Glioblastoma multiforme. The study focuses on different withanolides present in WS by highlighting the preliminary results obtained from their screening against GBM and other cancer cell lines. The massive scope for several other formulations like AshwaMAX that focus merely on the WA content has shown inhibition of growth in glioblastoma cells. The effects of other WS-specific phytochemicals and their potential on current clinical target molecules of GBM are yet to be explored. The lack of pre-clinical or *in-vivo* studies on the effect of WS phytochemicals in glioblastoma multiforme management opens a scope for in-depth studies and research with WS-specific phytochemicals. With developed ample pre-clinical research data demonstrating favorable outcomes, along with therapeutic effects of WS phytochemicals on resistant GBM sublines and tumor microenvironments, there is a considerable prospect for WS to be recognized as a revolutionary advancement in glioblastoma multiforme management. Summarizing, the combinational or synergistic effect of the *Withania*-specific phytochemicals could be another alternative approach to the therapeutic use of WS in glioblastoma multiforme therapy. As the quest to find a novel and cheap therapeutic strategy against GBM persists, interventions by means of various extracts and phytochemicals from WS may ultimately emerge as a precise management system for GBM.

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Data availability statement:

The data utilized in this review article are obtained from publicly accessible sources or referenced publications. The original resources can be accessed through the provided references for further analysis or replication purposes.

Author Contributions:

All authors participated in data curation, developing the methodology and writing the original draft of the article. Sohini Kulavi, Karan Iyer, and Debajit Dhar were responsible for conceptualization, formal analysis, investigation and reviewing, and editing subsequent versions of the article. Sohini Kulavi was responsible for visualization, while Arnab Kumar Ghosh and Jaya Bandyopadhyay were solely responsible for supervision and validation of the work.

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Chapter- 8

An Overview of Clothianidin, Dinotefuran and Thiacloprid on Aquatic Communities: Evaluating the Impacts of Environmental Risks Posed by Neonicotinoids

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Keywords: Neonicotinoids, Aquatic Environment, Impact on Animal.

Abstract:

Effective pest management is one of the potential methods to boost crop output because pest infestations account for more than 45% of the annual loss in food production. In order to combat pests and diseases spread by vectors, a wide range of pesticides must be applied to crop plants. Currently, India is the largest producer of pesticides in Asia and ranks twelfth in the world for the use of pesticides. Numerous factors, including chemical classes, functional groups, modes of action, and toxicity, can be used to categories pesticides. Insecticides stand out because they are made to be poisonous to the organisms they are intended to kill. They may be hazardous to non-target creatures, such as fish, because many of their targets are substantially conserved across many taxa. The majority of insecticides used worldwide now are neonicotinoid pesticides, which make up 26% of the insecticide marketed globally. Neonicotinoid insecticides have historically been seen as the best alternatives to some insecticides (such as organophosphates and carbamates), in part because they were thought to have little environmental or non-target organism danger. They are nicotinic acetylcholine receptor agonists, which bind tightly to the nicotinic acetylcholine receptors (nAChRs) in the central nervous systems of insects. At low concentrations, they stimulate the nervous system; at higher concentrations, they block the receptors, cause paralysis, and cause death. Neonicotinoids are specifically more harmful to insects because they bind to insect nAChRs more strongly than they do to vertebrate nAChRs.

Introduction:

Growing enough food to feed the world's increasing population is a challenge, and the changing food habits of an expanding middle class across Asia have made it necessary to manage a wide range of insect pests in order to increase agricultural productivity and quality (Sparks, 2013; Ivanišová et al., 2022). In addition to its role in agriculture, insecticides are widely used in industry, households, and military to control insect pests that are disease vectors, suggesting its essential role in human life (Xiao et al., 2017; De et al., 2019; Saha et al., 2022). Several types of newly developing illnesses that pose a hazard to public health are spread by

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arthropod vectors, including ticks (like Lyme disease), sandflies (leishmaniasis), mosquitoes (malaria, dengue fever, yellow fever, encephalitis, filariasis, West Nile fever, and chikungunya) etc. The World Health Organization (WHO), as well as other scientific studies and publications, have provided ample evidence that the application of synthetic pesticides can significantly lower the incidence of insect-borne illnesses, including malaria (Himeidan et al., 2012).

Neonicotinoid sales have increased due to its high activity and persistent control qualities (Wakita et al., 2004). Neonicotinoids, when compared to other insecticides, are extremely soluble and thus absorbed by the plant due to their systemic nature. After prolonged exposure to sublethal dosages, they cause delayed mortality in arthropods, however they are not particularly hazardous to vertebrates (Sanchez-Bayo, 2014). Beyond their use in agriculture, neonicotinoids are used to control human and animal parasites such as bed bugs and fleas (Bass et al., 2018). Imidacloprid, acetamiprid, dinotefuran, thiamethoxam, and clothianidin are among the neonicotinoid pesticides. Due to their extensive usage against a wide range of sucking and certain chewing pests, neonicotinoid insecticides have seen the quickest growth in the last ten years in the field of crop protection (Ensly, 2018). Similar to the naturally found alkaloid (S)-(−)-nicotine, all neonicotinoids function as agonists of the molecular target site, the post-synaptic nicotinic acetylcholine receptors (nAChRs), on the insect central nervous system (CNS) in a selective manner (Jeschke et al., 2008).

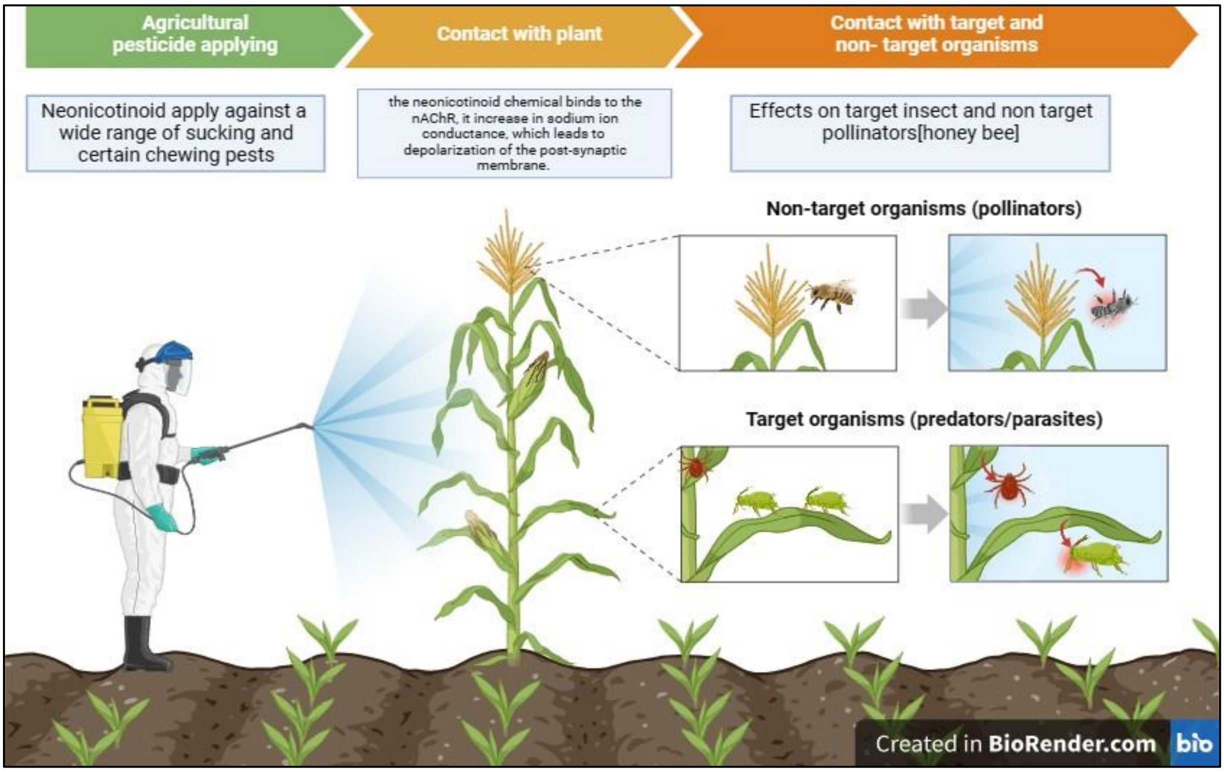


Figure 1. Neonicotinoid on Insects in Agriculture

Neonicotinoids are now well known to a large number of individuals due to media and online publications concerning bee reductions. Numerous studies have been conducted on this subject in recent years, and the data indicates that neonicotinoids' effects on bees and other pollinators are too significant to be disregarded (Osborne, 2012). In recent years, there has been much discussion about the potential cause of colony collapse disorder, with neonicotinoid insecticides receiving particular attention. The extent of the harm produced by these pesticides is debatable, though; some investigations indicate that bees are harmed by neonicotinoids in amounts commonly used in crops, while other papers state that the data is inconclusive (Guzman-Novoa, 2016).

Few people are aware of neonicotinoids' effects on aquatic environments since the discussion over them has been centered on bees. However, when we consider the implications for the greater aquatic ecosystem, they provide challenges to this ecosystem that may be more subtle in nature but more widespread in reach. In the present review, we have selected dinotefuran, clothianidin and thiacloprid owing to their distinct chemical features, in order to throw light on their effects in aquatic environment. The main ways that materials get into aquatic ecosystems are through surface runoff from rainy events, soluble or insoluble fractions carried by snowmelt, leaching into groundwater and subsequent subsurface discharge into wetlands and other surface waters, dust from talc and graphite from seeding drills, decomposition of effectively treated plants in lakes and streams, and deposition of treated seeds, soil, or spray drift into holes in the ground. Most surface water pollution is anticipated to occur from runoff following significant precipitation occurrences (Morrissey et al., 2015; Rangamani et al., 2023).

Chemical residues found in water are a continual threat to aquatic life since they are unable to escape it. The internal concentration of the insecticide, which in turn depends on its external concentration, the dynamics of each species, and its detoxifying capacity, determine how long it takes an organism to reach its death threshold (Hong et al., 2018). Fish inhabit almost all aquatic habitats and are extensively spread. Fish are a great model for environmental toxicological research in aquatic systems and chemical safety evaluation because they are a bio-indicator that is sensitive enough to changes in the aquatic environment (Dutta et al., 2014; Sarkar & Madhu, 2016; Sanchez-Bayo et al., 2016).

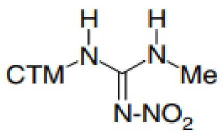
Neonicotinoids can be ingested by people who are not in close touch with them by means of fruits and vegetables that have been harvested from farm-land that has been treated with neonicotinoids. Neonicotinoids were found in 29 samples of fruits and vegetables, in 72% of the fruits and 45% of the vegetables (Borsuah et al., 2020). It has been discovered that neonics have effects on mammalian nAChRs that resemble those of nicotine. The operation of the human brain depends critically on these receptors, particularly throughout development and for memory, cognition, and behaviour. The capacity to bind to the most common subtype of nAChRs in mammals, the $\alpha 4\beta 2$, which is concentrated in the thalamus, is one unique feature of neonic toxicity. Changes in this neuroreceptor subtype's density have been linked to a number of illnesses affecting the central nervous system, such as depression, schizophrenia, Parkinson's disease, and Alzheimer's disease (Cimino et al., 2017; Haloi et al., 2023).

Structure of Neonicotinoids

Neonicotinoids synthesized in the past few decades have four chemical structures: an aromatic heterocyclic group; elastic bonds; hydro heterocyclic groups, often known as guanidine/amidine groups; and an electron-withdrawing group. Furthermore, by altering the structures of the aforementioned compounds to substitute a sulfonamide functional group or its cyclical equivalent for a cyano- or nitroguanidine/amidine group, new neonicotinoid derivatives are constantly being produced (sulfonamide neonicotinoids, e.g., sulfoxaflor) (Buszewski et al., 2019).

Clothianidin

Clothianidin, also known as (E)-1-(2-chloro-1,3-thiazol-5-yl-methyl)-3-methyl2-nitroguanidine, is a novel nicotinic insecticide with outstanding efficiency, safety, and selectivity. Its impact was comparable to that of the nicotinic acetylcholine receptor, causing shock, gastrointestinal toxicity, and internal absorption (Panget et al., 2020). Clothianidin is mostly used in rice, vegetables, fruit trees, and other crops to control hemipteran, coleopteran, dipteran, and some lepidopteron pests. For a wide range of pest species belonging to the groups Orthoptera, Isoptera, Diptera, Lepidoptera, Homoptera, and Heteroptera, clothianidin shows good control efficacies in modest doses. The vast insecticidal spectrum, strong activity at low dosage, long-term control impact, outstanding systemic action, numerous treatment options, and high crop safety may be summed up as the biological qualities of clothianidin. In insect nicotinic receptors, clothianidin binds with a high affinity (Wakita, 2011).

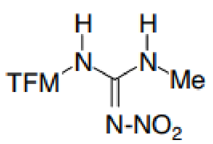


Clothianidin (TI-435, 2002)[a]
(H, Me)

Structure 1. Clothianidin

Dinotefuran

Mitsui Chemicals Agro created dinotefuran, also known as (RS)-1-methyl-2-nitro-3-(tetrahydro-3-furylmethyl) guanidine, a neonicotinoid pesticide. Furthermore, dinotefuran was a chiral insecticide that has two isomers: R-dinotefuran and S-dinotefuran (Wakita et al., 2003). The LC_{50} values of R-dinotefuran and S-dinotefuran in soil were found to be 8.786 and 3.286 mg/kg, respectively, while the toxicities of S-dinotefuran and R-dinotefuran to earthworms differed by 2.67-fold. Different from other neonicotinoids, dinotefuran offers a tetrahydrofuran (THF) moiety that contains a chloropyridine or chlorothiazole ring, which is thought to be



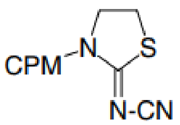
Dinotefuran (MTI-446, 2002)[a]
(H, Me)

Structure 2. Dinotefuran

a crucial structural component for the neonicotinoid activity. With the use of the cholinergic ester moiety as a lead structure, a successful molecular design technique, dinotefuran with the cyclic ether THF functional group has been discovered (Zhang et al., 2022).

Thiacloprid

Thiacloprid is a neonicotinoid pesticide used to protect vegetables, orchards, tea, maize, and oilseed rape seeds (Uneme, 2011). Thiacloprid was created to be used on agricultural crops to control insects, particularly aphids and small flies. It is a product used to protect oilseed rape, fruit trees, vines, vegetables, potatoes, and ornamental woods against animal and insect pests and flies. Thiacloprid molecules are polar, and its white powder is soluble in water as well as organic solvents such as acetone, dichloromethane, dimethyl sulfoxide, and ethanol. Because Thiacloprid is stable throughout the pH range 4-9, pH has no effect on solubility. The low partition coefficient (log P = 1.26) suggests that it is poorly soluble in fat and has poor absorption and distribution in the body (Verebova et al., 2021).



Thiacloprid (YRC2894, 2000)[a]
(CH_2CH_2)

Structure 3. Thiacloprid

Interaction and selectivity mechanism of Neonicotinoids Insecticides Dinotefuran, Clothianidin and thiacloprid:

Neonicotinoids are nicotinic acetylcholine receptor (nAChR) agonists found in insect nerve synapses. They disturb invertebrate brain activity by binding to post-synaptic nAChRs and functionally interfering with normal neural activity. When the neonicotinoid chemical binds to the nAChR, it produces an increase in sodium ion conductance, which leads to depolarization of the post-synaptic membrane. Unlike acetylcholine, neonicotinoids' action is not restricted by acetylcholinesterase; as a result, neonicotinoids cause extended neuronal activation, which leads to hyper-excitation of the insect nervous system, followed by convulsions, paralysis, and death. The binding of neonicotinoids to nAChRs is thought to be mostly irreversible and cumulative over time. Invertebrates can be harmed by even modest dosages over time, causing stunted growth and development, changed behaviour, restricted mobility, diminished adult emergence, and reduced eating. Furthermore, because of the conserved nature of insect neurophysiology, neonicotinoids impact both pest and non-target species, albeit to varied degrees (Cavallaro et al., 2017). There are several subtypes of nicotinic receptors found in mammalian tissue. The various subtypes are made up of various combinations of subunits. Nicotinic receptors are found in animals' autonomic ganglia, skeletal muscle, spinal cord, and several brain areas. Because of the differing binding qualities of the various receptor subtypes, neonicotinoids have substantially lower action in vertebrates than in insects (Ensley, 2018).

Toxicity of dinotefuran, clothianidin and thiacloprid towards the aquatic environment:

Insecticides, particularly neonicotinoids, have caused surface and ground water contamination in water bodies near high agricultural zones where neonicotinoids are often employed in recent years. Neonicotinoids applied to soil decompose between 25.4% to 80.9%; however, the proportion varies depending on application rate and soil type. This indicates that between 20% and 75% of neonicotinoids used are accessible for transfer to surface waterways via runoff or leaching into groundwater. Furthermore, following pesticide treatments, sprayer equipment typically holding a combination of the residue may result in offsite runoff and have a harmful impact on the environment if not properly controlled (Madhu et al., 2022). Furthermore, there is rising worry about groundwater contamination caused by pesticides used in agricultural businesses and urban areas (Ensley, 2018).

Dinotefuran

Although dinotefuran has a high environmental safety in water, its high solubility and persistence significantly enhance its risk to aquatic life. Dinotefuran has a solubility of 40 g/L at 20 °C and a maximal half-life of 100 days. As a result, it is critical to assess the possible harm of dinotefuran to aquatic creatures (Pang et al., 2020). Furthermore, dinotefuran has a lengthy half-life in acidic, neutral, and slightly alkaline fluids, with a maximum half-life of more than a year (Verebova et al., 2019).

Clothianidin

Due to its poor soil binding, high water solubility, and persistence in soil, most Clothianidin maintained in soil is more likely to move to groundwater, streams, wetlands, and ponds. The Clothianidin has been found at quite high levels in a variety of aquatic habitats, including groundwater, wastewater treatment plant effluents, and wet land ponds (Yang et al., 2022). Clothianidin exhibited modest toxicity in carp, with a 96-hour LC_{50} greater than 100 mg/L. Clothianidin was also shown to be non-toxic to algae (72 hr EC50: 177 mg/L) and Daphnia magna (48 hr EC_{50}: 40 mg/L). These findings indicate that clothianidin has no effect on aquatic organisms (Velisek et al., 2018).

Thiacloprid

Thiacloprid has high-water solubility (184-186 mg/L) and a relatively low log Kow (1.26) at 20°C. Thiacloprid is stable in anaerobic aquatic conditions with a half-life of over one year and degrades in aerobic aquatic conditions with a half-life of 10-63 days (Stara et al., 2021). Thiacloprid has been shown in experiments to produce a variety of pathological and behavioral abnormalities in aquatic creatures. Significant alterations in antioxidant activity and aggressive behavior in crayfish, as well as reduced weight and length of carp (*Cyprinus carpio*) bodies, were observed (Akter et al., 2023).

Persistence of neonicotinoids in soil, surface water and ground water:

Because neonicotinoids are extremely soluble in water, they can easily migrate downhill and stay in the soil for months to years, depending on formulations, soil texture, organic matter content, management techniques, and climatic conditions. The downward flow often occurs from the topsoil, which is thought to be the zone with the most microbial activity; therefore, neonicotinoid residues may constitute a hazard to soil microorganisms (Pietrzak et al., 2020). Neonicotinoid insecticides are susceptible to a variety of processes before reaching groundwater, including sorption, biodegradation/biotransformation, and chemical transformation, which can slow migration rates and/or lower concentrations and loads (Ramadevi et al., 2022).

Because neonicotinoids have such a long half-life in soils and are water-soluble, they can deposit and flow into surface and groundwater. So, there is a correlation between bird losses and the presence of neonicotinoids in water, and they also harm fisheries by drastically cutting yields. The discovery of neonicotinoid residues in surface water systems up to 225 g/L, is cause for worry because aquatic invertebrates are key members of many fresh water bodies, and certain species are especially susceptible to neonicotinoids (Goulson, 2013).

Economic benefits of neonicotinoids:

There is abundant evidence that neonicotinoids can provide effective control of a broad range of insect pests. It is less clear to what extent the widespread adoption of neonicotinoids has contributed to yield increases in farming or whether neonicotinoids offer economic benefits compared to alternatives. Yields per hectare of almost all arable crops have increased markedly over the last 60 years as a result of many changes, including improved crop varieties, widespread use of artificial fertilizers, new agronomic techniques and the development of successive generations of pesticides. However, the pace of yield increases has slowed, and yield increases in the last 20 years in developed countries have been modest, with some crops such as oilseed rape showing no increase coincident with the introduction of neonicotinoids. Where yield gains have occurred in recent years, it is difficult to distinguish the role of neonicotinoids from the effects of other agronomic practices changes (Budge et al, 2015).

Impact on Animal Health:

Oxidative stress

Increased lipid peroxidation, reduced glutathione levels, and altered activity of important antioxidant enzymes (e.g., catalase, superoxide dismutase, and glutathione peroxidase) are all symptoms of neonicotinoid exposure. Thiacloprid raises nitric oxide levels in polymorphonuclear leukocytes and plasma from rats exposed to the drug. Curcumin and vitamin C, for example, can protect tissues against neonicotinoid-induced oxidative damage. Based on the findings, oxidative stress generated by neonicotinoid pesticide exposure has been postulated to have a significant role in their toxicity in non-target species (Wang et al, 2018).

Reproductive Toxicity

Multiple studies have found that neonicotinoids have negative reproductive and developmental consequences in mammals, including greater rates of embryo loss, early delivery, lower pregnancy rates, lower sperm production and function, lower child weight, and stillbirth. Clothianidin substantially raised amounts of thiobarbituric acid-reactive compounds, cholesterol, and palmitic, linoleic, and arachidonic acids in the testis of male rats, but did not promote sperm DNA breakage (Han et al, 2018).

Metabolite toxicity

Metabolites of neonicotinoid chemicals can be more hazardous than the parent compounds. Metabolites generated by the removal of nitro- or cyano-functional groups, in particular, have the potential to be more selective and to bind more strongly to mammalian nAChRs. Desnitro-imidacloprid, for example, exhibits an affinity for mammalian nAChRs equivalent to nicotine. When the neonicotinoid is converted to the desnitro metabolite, the selectivity ratio for insects vs vertebrates decreases from 565 to 0.005. Studies on Mice shown that imidacloprid and desnitro-imidacloprid, like nicotine stimulates the extracellular signal-regulated kinase cascade and cause intracellular calcium mobilization in rat PC12h cells (Wang et al, 2018).

Endocrine Effects

The effects of neonicotinoids on endocrine disruption have been studied in vitro. Thiacloprid inhibits aromatase (CYP19) activity in a fetoplacental steroidogenesis model. Estrone and estradiol production increased, whereas estriol production decreased. Estrogens are vital during pregnancy, and alteration in estrogen production may damage the fetus as well as the mother's health. Evidence suggests that neonicotinoids are metabolized by CYP3A7, which affects the conversion of dehydroepiandrosterone sulphate to estriol and might explain the observed reduction in estriol production. This conclusion is concerning since enhanced estrogen synthesis in tumors has been proven to stimulate cancer cell proliferation, with aromatase playing an important role in this process (Zuscikoa et al, 2023).

Conclusion

The present study will provide the toxicological properties of three individual neonicotinoids: dinotefuran, clothianidin, and thiacloprid. Farmers when suggested to use these pesticides, they must try to use it at safer dose for the protection of aquatic ecosystem. In addition, the pesticide-based method to control insect pest must be replaced by some other eco-friendly and cost-effective approaches. The outcomes of present study suggest reducing the pesticides usage which will help to protect the aquatic biodiversity at their natural habitat.

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Chapter- 9

An Overview of Fishermen Cooperatives in West Bengal with Special Reference to Murshidabad District

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Keywords: Fishery, Fishermen, Cooperative, Socio-economic development

Abstract:

Fishery and aquaculture have immense potential in our country. This sector can play a vital role in boosting the economy as well as ensuring food security for the growing population. Fishermen cooperatives can be utilized for increased productivity in the fishery sector. The effective operation of the primary fishermen cooperatives can improve the socio-economic profile of the poor fishermen. West Bengal is endowed with rich fishery resources and formed nearly one thousand fisherman cooperatives. Murshidabad district has a large number of fishermen cooperatives among the districts of West Bengal. This district also has huge fishery resources. The secondary data shows that fish production is declining in Murshidabad and there is a deficit of production which is unable to fulfil the growing demand. Studies on the performance of fishermen cooperatives in various parts of the country showed that these can be utilized as effective tools for increased productivity and improved economy. In view of the above, the present study deals with the objective of a thorough understanding of the functioning of fishermen cooperatives in the district and searching for suitable remedial measures for their improvement. The study may have a large impact on the rural development of the district, particularly the development of the poor fishers, mostly belonging to the socially and economically backward scheduled caste category.

Introduction:

Fishery sector occupies a very important place in the socio-economic development of the country for its contribution to economic growth and food security. This sector is recognized as a powerful income and employment generator for the poor people of rural areas. Fishery and aquaculture potentially contributed to the national income, nutritional security, employment opportunities, social objectives and export earnings (Dhara et al., 2016; Mallick, 2017; Eseroghene & Ikechukwu, 2018). In India, this sector showed an impressive transformation from a traditional subsistence activity to a well-developed diversified commercial enterprise with vast untapped potential.

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Cooperative society is an organization of a group of people with collective responsibilities and thoughts for the development of the needy, especially the underprivileged. Cooperatives helped in the development of agriculture, banking, credit, agro-processing, storage, marketing, dairy, fishing, and housing. Its network covers 85% of rural households. It occupies a key position in agricultural development with support in resource and input use, harvesting of water resources, marketing channels, storage facilities, distribution channels, value addition, market information, and a regular monitoring network system. Cooperatives are also engaged in economic activities like disbursement of credit and distribution of agricultural inputs like seeds, fertilizers and agro-chemicals etc. cooperative have inherent advantages in tackling the problems of poverty alleviation, food security and employment generations (Dubey et al., 2009).

As the fishermen generally come from weaker sections of society, they lack necessary monetary resources, knowledge of technological advancements and organizational capacity required for better fish production, storage, processing and marketing. Due to low income, they usually borrow money from fish merchants at high rates of interest. Thus, there is a vicious circle of indebtedness fostering exploitation. Formation of a fishermen cooperative society can solve all these problems and fishermen in different countries have adopted the cooperative system of working to improve their fisheries all around as well as develop their socio-economic conditions (Mishra, 1997).

Fishermen Cooperatives in West Bengal:

West Bengal was the 2nd State in India, which formed fishermen cooperatives in 1918. Since then, a large number of fishermen cooperatives have been formed in West Bengal involving about one lakh fishers who mostly belong to socially, educationally and economically backward communities.

The following table shows the number of fishermen co-operative societies (Inland and Ornamental) in West Bengal as of 31.03.2016.

Table 1: Statistics on Fishermen Cooperatives in West Bengal (Inland)*.

Sl No.	District	CFCS	PFCS Category			Total	Effective water area (in ha)	Total number of members
			A	B	C			
1	Darjeeling	0	1	0	2	3	3	400
2	Jalpaiguri	1	0	15	0	15	431	4000
3	Cooch Bihar	1	37	12	15	64	3414	14073
4	Uttar Dinajpur	1	0	0	22	22	134	5000
5	Dakshin Dinajpur	1	12	0	0	12	156	5796
6	Malda	1	75	13	5	93	3188	14671
7	**Murshidabad**	**1**	**24**	**13**	**76**	**113**	**21425**	**19312**
8	Nadia	1	39	31	27	97	7760	13056
9	Birbhum	1	11	3	24	38	619	814
10	Bardwan	1	22	8	28	58	222	4611
11	North 24 Parganas	1	44	14	14	72	1727	8526
12	South 24 Parganas	1	36	28	38	102	966	3512
13	Hooghly	1	15	7	14	36	202	2115
14	Howrah	1	13	0	0	13	121	738
15	Purulia	1	0	0	49	49	6527	5919
16	Bankura	2	4	6	11	21	43	2630
17	Purba Medinipur	1	32	26	11	69	2070	2477
18	Paschim Medinipur	1	19	6	4	29	93	4997
	Total	**18**	**384**	**182**	**340**	**906**	**49101**	**112647**
*Source: Hand Book of Fisheries Statistics 2015-16, Govt. of WB.								

In Marine Sector Fishermen co-operative societies in West Bengal as of 31.03.2016 are as follows:

Table 2: Statistics on Fishermen Cooperatives in West Bengal (Marine)*.

Sl No.	District	CFCS	PFCS Category			Total	Effective water area (in ha)	Total number of members
			A	B	C			
1	South 24 Parganas	1	16	0	0	16	5730	
2	Purba Medinipur	1	7	6	52	66	4135	
	Total	2	23	6	52	82	9865	
*Source: Hand Book of Fisheries Statistics 2015-16, Govt. of WB.								

Fishermen Cooperatives in Murshidabad:

The Murshidabad district has the highest number (113 Nos.) of Primary Fishermen Cooperative societies in West Bengal involving 19,312 members who are engaged in fish production covering an area of 21,425 ha. The number of ornamental fish production units in Murshidabad is 12. The number of water bodies with an area of five acres and above under the control of PFCS in Murshidabad is 118, having a total water area of 7316.73 ha (Statistical Handbook on fisheries 2015-16, Govt. of WB). However, the data found in the record of the Fishery Department of Murshidabad is somewhat different. The Record shows 101 registered Primary Fishermen Cooperative Societies (PFCS) in Murshidabad. The PFCS is categorized as per Audit gradation into 3 categories viz. Category A, B and C. As per the statistical Hand Book (2015-16) of Govt. of W.B., there are 24 A, 13 B and 76 C category PFCS in Murshidabad.

The Murshidabad District of West Bengal is also highly rich in freshwater resources. Among the district-wise impounded freshwater area, Murshidabad, with 28,348 ha, is the 3rd highest in West Bengal, after South 24 Parganas, with 49,237 ha and Burdwan, with 31,180 ha. A number of rivers in the district are 14 covering a total length of 912 KM and a number of canals is 914 which covers an area of 2,138 KM. Total number of water bodies with an area of five acres and above in the district is 122 which covers an area of 7,751 ha. Total fish cultivable area in the district is 20,599 ha. In Murshidabad, the Number of fishing villages is 109, where 21,673 families live. The total fisher folk population of the district is 3,53,174; most of whom belong to socially, educationally and economically backward scheduled caste category. Murshidabad district has the highest number of fisher folk population in SC category in West Bengal. Instead of the presence of these vast resources, fishery production in the state is declining from 2011-12 to 2014-15 and there is a deficit of production, unable to meet the demand of the district (Statistical Hand Book of Fisheries, Govt. of West Bengal, 2015-16). These huge fishery resources can be properly utilized for increased productivity by making the effective operation and management of the fishermen cooperatives of the district. So, there is a need to study the fishermen co-operatives for developing mechanisms for effective utilization of the freshwater resources and the large number of semi-skilled fishermen of the district to meet the growing demand for fish as well as improvement of socio-economic condition of the fishers.

Table 3: Statistics on PFCS in Murshidabad District*.

Sl No.	Block	Name of the PFCS	Registration No. & Date	Full Postal Address	No. of members	1st AGM held on	Last AGM held on	Statutory Audit completed up to	Water area (in hectare)	Category
1	Berhampore	Balarampur FCS Ltd.	No.43 dt. 27/11/1974	Vill+ P.O-Balarampur, Berhampore	85	-	29/6/2013	2011-12	3.68	B
2	Berhampore	Beel Bishnupur Agragami FCS Ltd.	No.D/F 27 dt. 09/11/1987	Vill-Bishnupur, P.O-Cossimbazar, Berhampore	103	-	3/4/2012	2011-12	30	A
3	Berhampore	Bhakuri MMSLtd.	No.69 dt. 14/11/1955	Vill-Bhakuri, P.O-Chaltia,Berhampore	92		28/5/2014	2011-12	30	A
4	Berhampore	Cossimbazar Manindranagar FCS Ltd.	No.16 dt. 30/04/1956	Vill+ P.o-Cossimbazar, Berhampore	162		27/6/2014	2011-12	30	A
5	Berhampore	Gandhi colony FCS Ltd.	No. D/F 47 dt. 02/03/1989	Vill- Gandhi Colony , P.o-Berhampore	163		20/03/1996	2001-02	Nil	C
6	Berhampore	Kharsadanga FCS Ltd.	No. 19 dt 11/04/1972	Vill-Kharsadanga, p.o-Boaliadanga, Berhampore	78		3/11/2011	2011-12	4	C
7	Berhampore	Krishnamati FCS Ltd.		Vill-Krishnamati, P.o-Berhampore	300		29/10/2010	2010-11	6.57 & 5 Km river	B
8	Berhampore	Kunjaghata FCS Ltd.	No. 65 dt. 08/10/1955	Vill-Kunjaghata,P.O- Khagra, Berhampore	147		25/04/2003	1999-2000	1 Km river	C

9	Berhampore	Rangamati Chandpara FCS Ltd.	No. 2 dt 15/04/1954	Vill-Chiruti,P.O-Kodla, Berhampore	153		3/5/2013	2010-11	50	A
10	Berhampore	Satui Chaourigacha FCS Ltd.	No. 16 dt 14/02/1955	Vill+P.O-Satui, Berhampore	671		22/06/2012	2010-11	36.4	A
11	Berhampore	Paharpur FCS Ltd.	No. 58 dt 14/12/1958	Vill- Paharpur, P.O- Bali Ratanpur, Berhampore	167		21/06/2012	2011-12	150	B
12	Berhampore	Srirampur FCS Ltd.	No.15 dt 15/11/1973	Vill-Srirampur P.O- Nowda Panur, Berhampore	141		1/6/2012	2011-12	22	B
13	Beldanga-I	Andiron FCS Ltd.	No.7 dt 02/07/1952	Vill- Andiron, P.O-Hareknagar,	263		4/4/2014	2010-11	56.13 acre	A
14	Beldanga-I	Benadaha FCS Ltd.		Vill- Benadaha P.O- Mudda	239		2/7/2007	2006-07	35.2	B
15	Beldanga-I	Bhanderdaha FCS Ltd.	No.1 dt 18/09/1978	Vill- Pilkhana, P.O-Maniknagar	139		19/06/2013	2010-11	600	A
16	Beldanga-I	Mahula FCS Ltd.	No.55 dt 05/08/1955	Vill+P.O-Mahula	242		12/3/2014	2008-11		B
17	Beldanga-I	Sujapur Union FCS Ltd.	No.64 dt 07/10/1955	Vill+P.O-Sujapur	160		15/09/2010	2010-11	20	A
18	Beldanga-II	Shaktipur Rampara FCS Ltd.	No.63 dt 03/10/1955	Vill+P.O-Shaktipur	652		22/05/2014	2011-12	196	A
19	Hariharpara	Beharia FCS Ltd.		Vill+P.O-Beharia			18/05/2010	2009-10	35	A
20	Hariharpara	Kaludiar Ramkrishnapur FCS Ltd.		Vill-Ramkrishnapur, P.O-Tantipur	170					C

21	Hariharpara	Kharia Kumradaha FCS Ltd.	No. 66 dt19/10/1955	Vill- Kumradaha, P.O- Rajdharpara	154		10/1/2012	2011-12	60	B
22	Hariharpara	Sirpur FCS Ltd.	No.09 dt 23/07/1962	Vill- Sirpur, P.O- Rainda	42		4/5/2013	2012-13	10	B
23	Nabagram	Gopegram FCS Ltd.		Vill- Gopegram, P.O- Rainda	67		23/04/2009	2008-09		B
24	Nabagram	Gura Singer FCS Ltd.	No.54 dt 05/08/1955	Vill- Gopegram, P.O- Choan	74		21/08/2012	2011-12		A
25	Nabagram	Panchgram FCS Ltd.		Vill+p.O- Panchgram	79		10/2/2009	2008-09	6.8	B
26	Nabagram	Rasulpur Hazbibidanga FCS Ltd.		Vill- Saiyadpur, P.O- Rasulpur	101		16/03/2010	2008-09		B
27	Nabagram	Telkar Dafarpur FCS Ltd.	No.138/64 dt 22/12/1964	Vill-Dafarpur, P.O- Telkar	96		25/01/2013	2011-12	15	B
28	Nabagram	Daspara FCS Ltd.	No.71 dt 03/01/1963	Vill-Daspara, P.O- Mahirul Anantapur						C
29	Nowda	Baliratanpur Sanyasidanga FCS Ltd.	No.53 dt 03/08/1955	Vill-Ratanpur, P.O- Tungi	256		30/06/2011	2011-12	60	B
30	Nowda	Goghata FCS Ltd.	No.17 dt 09/05/1956	Vill+ P.O- Goghata	270		8/11/2013	2011-12	95	B
31	Nowda	Nabindoba Ramnachandpur FCS Ltd.	No.52 dt 20/01/1975	Vill+ P.O- Kedarchandpur	493		28/07/2012	2011-12	50	B
32	Nowda	Sarbangapur FCS Ltd.	No.21 dt 16/05/1956	Vill+ P.O- Sarbangapur	235		30/12/2013	2011-12	30	C
33	Nowda	Tungi FCS Ltd.	No.04 dt 12/11/1961	Vill+ P.O- Tungi	125		22/04/2012	2011-12	112	C

34	Nowda	Sabdarnagar FCS Ltd.	No.46 dt 18/04/1962	Vill+ P.O- Trimohini	129		30/12/2013	2011-12	110	C
35	Domkol	Ambarpur Madhurkul FCS Ltd.	No.77 dt 15/12/1960	Vill- Ambarpur, P.O- Madhurkul	261		10/1/2014	2012-13	270	C
36	Domkol	Bhagirathpur Haldarpara FCS Ltd.		Vill+ P.O- Bhagirathpur	265					B
37	Domkol	Daserchak MSS Ltd.	No.28 dt. 17/12/2004	Vill- Daserchak, P.O- Paikmary	96		28/11/2013	2012-13	271	A
38	Jalangi	Chanderpara FCS Ltd.	No.1 dt 20/07/1972	Vill- Chanderpara, P.O- Sahebrampur	162		25/03/2014	2012-12	35	B
39	Jalangi	Jalangi FCS Ltd.		Vill+ P.O- Jalangi	357					B
40	Jalangi	Kaliganj FCS Ltd.	No.12 dt 05/01/1963	Vill+ P.O- Kaliganj	130		10/3/2012	2011-12	103	A
41	Jalangi	Kazipara FCS Ltd.	No.70 dt 24/05/1975	Vill+ P.O- Kazipara	156		31/04/2012	2011-12	9.4	A
42	Jalangi	Khairamari FCS Ltd.	No.11 dt 22/03/1956	Vill+ P.O- Kkairamari	528		3/9/2011	2011-12	286	A
43	Jalangi	Sagarpara Mangalbari FCS Ltd.	No.17 dt 15/10/2004	Vill+ P.O- Sagarpara	62		30/03/2012	2011-12	40	A
44	Farakka	Nayansukh FCS Ltd.	No.26 dt 23/06/1972	Vill+ P.O- Nayansukh	1077		13/06/2012	2011-12	143	B
45	Raghunathganj-I	Gankar FCS Ltd.	No.56 dt 30/03/1949	Vill+ P.O- Gankar	160		9/12/2011	2010-11	15	B
46	Raghunathganj-I	Pragatisil MSS Ltd.	No.DF/3 of 98-99 dt 30/07/1998	Vill- Pratappur colony, P.O- Raghunathganj	25		28/06/2014			A

47	Raghunathganj-I	Raghunathganj FCS Ltd.		Vill+ P.O- Raghunathg-anj	630					B
48	Raghunathganj-II	Krishnasail Mahalderpara FCS Ltd.	No.12 dt 17/04/1973	Vill+ P.O- Krishnasail	44		28/06/2012	2011-12	15	B
49	Raghunathganj-II	Giria FCS Ltd.	No.18 dt 09/11/1945	Vill-Giria, P.O- Maithipur	390		13/01/2014	2011-12		B
50	Raghunathganj-II	Brahmamtuli Piyarpur Bhagirathi FCS Ltd.	No.DE/55 of 2006-07 dt 16/10/2006		57		2/1/2012	2011-12		B
51	Sagardighi	Manigram Anchal MSS Ltd.		Vill+ P.O- Manigram	63				2.5	B
52	Sagardighi	Singeswari FCS Ltd.	No.15 dt10/02/1986	Vill- Singeswari, P.O- Dasturhat	161		13/09/2006	2006-07		B
53	Sagardighi	Ultadanga Dogachi Damos FCS Ltd.	No.DF/59 dt 13/06/1989	Vill- Ultadanga, P.O- Pilki	149		25/07/2005		6.96	B
54	Samserganj	Dhulian MSS Ltd.		Vill+P.O- Dhulian	152					C
55	Samserganj	Gangapathpur Padmandi Bonafied FCS Ltd.		Vill- Dhusaripara, P.O- Nimtita	1610		4/4/2010	2009-10	Padma River part	B
56	Suti-I	Ramkantapur FCS Ltd.		Vill+P.O- Ramkantapur	75					C
57	Suti-I	Aluani FCS Ltd.		Vill-Aluani, P.O- Bansabati	103				100	C
58	Suti-I	Bahutali FCS Ltd.	No.53 dt 02/04/1974	Vill+P.O- Bahutali	153		21/03/2004	2011-12		B

59	Suti-I	Nazipur FCS Ltd.	No.48 dt 21/031978	Vill- Nazipur, P.O-Chhhabghati	190		15/04/2011	2011-12	10	C
60	Suti-I	Ahiran Deshbandhu FCS Ltd.		Vill+ P.O-Ahiran	249				70	C
61	Suti-I	Azgarpara FCS Ltd.		Vill+ P.O-Agarpara	24					B
62	Suti-I	Hilora FCS Ltd.		Vill+ P.O-Hilora	25					C
63	Suti-I	Mahisal FCS Ltd.		Vill+ P.O-Mahisal	84					C
64	Suti-II	Chhabghati FCS Ltd.	No.55 dt 20/03/1961	Vill-Malopara, P.O-Chhabghati	100		6/2/2010	2009-10	10	B
65	Suti-II	Jagtai Ganga FCS Ltd.	No.75 dt 19/02/1997	Vill+P.O-Jagtai	408		28/03/2010	2010-11	river	B
66	Bharatpur-I	Bharatpur GP FCS Ltd.	No.DF 94 dt 14/06/1991	Vill+P.O-Bharatpur	53		2/6/2011	2010-11	14.4	B
67	Bharatpur-I	Sijgram GP FCS Ltd.	No.ADF/1 of 2014-15 dt 17/07/2014	Vill-Samunsurpur, P.O-Sahapur	26					
68	Bharatpur-I	Amlai Gram Panchyat FCS Ltd.	No.DF3 of 2011-12 dt 29/12/2011	Vill-Bhaluipara, P.O-Amlai	48		7/5/2012	2011-12	53.4	A
69	Bharatpur-II	Talibpur GP FCS Ltd.		Vill+P.O-Talibpur	36					C
70	Burwan	Karun Narun Anchal FCS Ltd.	No.6 dt 04/1/2/1972	Vill+P.O-Rajhat	161		20/09/2001	2003		B
71	Burwan	Sundarpur FCS Ltd.		Vill+P.O-Sundarpur	20					C

72	Burwan	Beel Langolhata FCS Ltd.		Vill-Langolhata, P.O-Dakbanglo	93					B
73	Burwan	Durgi Matsojibi Samabai Samiti		Vill+P.O-Rajhat						C
74	Kandi	Amitya FCS Ltd.	No.14 dt 13/08/1976	Vill-Amitya,P.O-Natungram	151		20/02/2008	2011-12	part of Babla river	B
75	Kandi	Chandnagar FCS Ltd.	No.59 dt 18/09/1955	Vill-Chandnagar,P.O-Mahadia	444		28/06/2012	2011-12	30	A
76	Kandi	Gatla FCS Ltd.		Vill+P.O-Gatla	94			2009-10	6.00 & 3.00 Km	A
77	Kandi	Gobarhati FCS Ltd.	No.1 dt 06/01/1950	Vill+P.O-Gobarhati	100		15/04/2012	2011-12		A
78	Kandi	Jibanti FCS Ltd.	No.8 dt 23/07/1962	Vill+P.O-Jibanti	109		17/09/2012	2011-12	10	A
79	Kandi	Kandi FCS Ltd.	No.59 dt 05/12/1958	Vill+P.O-Kandi	22		15/02/2010	2011-12	12	A
80	Kandi	Nowpara Tapsil FCS Ltd.		Vill- Nowpara, P.O-Kumar Sandhya	69		5/3/2012	2011-12		A
81	Kandi	Paschim Bahara FCS Ltd.	No. 140/93 dt 22/03/1993	Vill- Bahara P.O-Kandi	69		5/3/2012	2011-12		A
82	Kandi	Patendra FCS Ltd.	No. 12 dt 29/04/1970	Vill- Patendra P.O-Gobarhati	118		11/7/2010	2010-11		A
83	Kandi	Ruppur FCS Ltd.	No.03 dt 25/03/1971	Vill- Ruuppur, P.O-Jemo Kandi	50		2/1/2011	2011-12	3.1	A

84	Khargram	Beel Patan FCS Ltd.		Vill+P.O-Garutila	289		26/06/2011	2006-07		B
85	Khargram	Nagar Dhibar FCS Ltd.	No.3 dt 20/01/1951	Vill+P.O-Nagar	307		27/03/2012	2011-12		B
86	Khargram	Sujapur MSS Ltd.	No.135 dt 29/09/1964	Vill- Sujapur, P.O-Gokarna	210		5/3/2001	2000-01		B
87	Bhagwangola-I	Adarsha Birendranagar FCS Ltd.		Vill+ P.O-Birendranagar Colony	100					C
88	Bhagwangola-I	Arizpur FCS Ltd.		Vil- Arizpur, P.O-Sitesh Nagar	149					B
89	Bhagwangola-I	Dangapara FCS Ltd.	No.22 dt 05/12/1972	Vil-Dangapara, P.O-Mahisasthali	209		15/11/2011	2011-12	10	A
90	Bhagwangola-II	Akharinganj FCS Ltd.	No.1049H dt 17/07/1945	Vill+P.O-Akhariganj	217					C
91	Lalgola	Lalgola Padma FCS Ltd.	No. 57 dt 30/03/1949	Vill-Krishnapur, P.O-Lalgola	1292		14/08/2011	2011-12	2 bigha river Padma part	A
92	Lalgola	Natun Singha FCS Ltd.	No. 44 dt 27/06/1985	Vill- Natun Singha, P.O-Sadar Nasipur	1147		17/05/2014	2010-11	50	A
93	Lalgola	Chakmaharam GKS MSS Ltd.	No. DF/3 of 12-13 dt 21/06/2012	Vill-Chakmaharam, P.O-Rajarampur	12		9/5/2014		12.79 acre	A
94	Msd-Jiaganj	Kashiganj Basmathuhara FCS Ltd.	No. 52 dt 01/03/1949	Vill-Kashiganj, P.O-Jiaganj	427		22/05/2013	2012-13	20	A
95	Msd-Jiaganj	Lalbagh FCS Ltd.	No.71 dt 21/11/1960	Vill+P.O-Lalbagh	113		23/06/2012	2004-05		B

96	Msd-Jiaganj	Nowda FCS Ltd.	No.972 dt 26/03/1945	Vill- Nowda, P.O-Bangapara	199		15/06/2012	1987-88		C
97	Msd-Jiaganj	Prasadpur Mahadevtala MSS Ltd.	No.68 dt 10/12/1995	Vill-Prasadpur, P.O-Haribhanga	367		17/11/2011	2010-11		A
98	Raninagar-II	Char Rajapur MSS Ltd.	No.DF/8 0f 2012-13 dt 02/11/2012	Vill+P.O-Char Rajapur	70	2/1/2013	30/06/2015	2014-15	20-25 Km channel	C
99	Raninagar-I	Chakjama FCS Ltd.	No.973 dt 26/03/1945	Vill-Chakjama, P.O-Islampur	71		31/01/2003	2004-05		C
100	Raninagar-I	Gopinathpur FCS Ltd.	No.41 dt 07/03/1962	Vill+P.O-Gopinathpur	225		27/11/2009	2006-07		A
101	Sagardighi	Sagardighi Fishermen's Cooperative Society Ltd.	No.01/MSD/2017-18 dt 07/12/2017	Vill-Teghari Koyelpara, P.O-Kabilpur	35				12.8	C

*Source: Record of Fishery Department, Murshidabad, West Bengal, 2017.

Conclusion

In West Bengal, fishery is a sunrise sector and ample scopes are there for its improvement. Nearly one thousand fishermen cooperative societies with over one lakh fishermen as members can play a vital role in the production, processing and marketing of fish and other economically important aquatic organisms. The District Murshidabad with its huge water resources, large number of fishermen population and large number of fishermen cooperatives has the potential to reap maximum economic benefit by using proper management and modern technology in this field.

The secondary data received from various sources indicate that although fishery resources are huge in West Bengal, still there is the deficit in fulfilling the demand of the people of the State. Same phenomenon is also true in the case of Murshidabad district. The District has the 3rd largest water resource in West Bengal, but the production is below the demand level.

As various studies in different parts of India indicated that the Fishermen Cooperatives are very much helpful for enhancement of fish production and socio-economic development of fishers, efforts can be taken to strengthen these institutions. From the literature Survey, it is found that no serious studies have been conducted on the fishermen cooperatives in Murshidabad as well as in West Bengal in the recent past. There are variations in the statistical data related to fishermen cooperatives in the FISHCOPFED survey report, Statistical Handbook of Govt. of West Bengal and Record of fishery department of Murshidabad. The data related to fish production, profits, constraints, use of modern technology and socio-economic profile of the fishers under the cooperatives of Murshidabad are unavailable.

Hence, it is necessary to assess the present status of the fishermen Cooperatives in Murshidabad where the highest number of fishermen cooperatives has been formed in West Bengal and also to find out the scopes and prospects of these institutions.

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Chapter- 10

The Impact of Microplastics on Fish Poses a Threat to Human Health

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Keywords: Microplastics, fish, contamination, human, aquatic ecosystems, water pollution, plastics, freshwater ecosystems, toxic

Abstract:

With the growth of human population, the production and usage of plastics are also increasing. Overuse of plastics has adverse effects on the environment. Underwater plastics fragment into microplastics (MPs). This MP is a major cause of concern as a pollutant in aquatic ecosystems. Microplastic contamination is not a newly discovered problem, but it is still a crucial issue to discuss. MP exposure poses a great threat to fish health. MPs contamination can cause organ damage, toxic responses, behavioral changes, and so on. Additionally, MP ingestion by fish directly or indirectly affects human lives. Microplastics enter the human body in large amounts through fish consumption. The accumulation of microplastics within the human body has a wide range of toxicological and negative consequences. The control strategies for microplastic contamination are still in their infancy. More detailed study is needed about the nature and toxic effects of the MPs in order to mitigate their effects.

Introduction:

An aquatic ecosystem is an aquatic environment where living organisms live and interact with one another for shelter and nutrients. This ecosystem covers almost 71% of the Earth's surface and contributes about 50% of global productivity (Hader & Gao, 2023). Aquatic ecosystems also act as CO_2 sinks to mitigate climate change. According to aquatic ecologists, three trophic levels (phytoplankton, zooplankton and fish) represent the whole aquatic ecosystem (*Patra* & Madhu, 2009; Dutta et al., 2014; Meyers, 2019; Biswas et al., 2023). Fish are a major component of marine as well as freshwater habitats. They play a vital role in food chain dynamics, nutrient cycling, and ecosystem services. Fish also provides large-scale employment around the world. India itself contributes 8% of global fish production, becoming the 3rd largest fish-producing country (https://pib.gov.in/index.aspx). Fish also serve as one of the most essential animal protein sources. More than 1.5 billion people consume fish as food (https://www.greenfacts.org). This economically and nutritionally important species is likely to

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be under threat of pollution (Bhattacharya, 2015; Mondal et al., 2022). Several studies have reported in which fish are used as bioindicators of water pollution (Fierro et al., 2017). Heavy metals like cadmium and lead were also determined from fish bodies to evaluate the water pollution rate (Rashed, 2001; Madhu et al., 2022). There are several causes associated with the pollution of aquatic ecosystems. Industrialization, agricultural activities, overuse of pesticides, and sewage-related debris are mainly responsible for water pollution. Over the past several years, the increasing use of plastics has caused a significant environmental problem. Every day, our oceans are polluted by 8 million pieces of plastic, and almost 88% of the sea surface is covered by plastic waste (Condor Ferries, Plastic in the Ocean Statistics, 2020). The World Wildlife Fund (WWF) reported that plastic has become the reason for the deaths of 100,000 marine animals. Recently, microplastics (MPs) have become a topical issue as a prime pollutant in aquatic ecosystems. Enormous anthropogenic activities are one of the primary reasons for microplastic contamination in aquatic ecosystems (Alimba and Faggio, 2019). Naturally, plastics remain under water for centuries. During the time course, plastics undergo changes by UV radiation, biodegradation, or mechanical force of water to form small fragments of microplastics (Wang et al., 2021). These MPs have a severe impact on fish health. Microplastics contamination leads to damage to fish's organs like the intestine, liver, gill, and brain (Roy et al., 2022; Das et al., 2023; Bandyopadhyay et al., 2023). This may also alter metabolic balance, behavior, and reproductive health. Once fish ingest MPs, they may enter the food chain and transfer across the trophic levels of the food web. This results in toxic effects on the environment. MPs ingestion by fish also poses risks to human health, as fish and fishery products are the main path of microplastic contamination in the human diet.

What is microplastic?

In 2004, the term 'Microplastics' was first coined. Initially, microplastics were used to define smaller fragments of plastic particles. However, to date, there is no accurate definition to describe microplastics (Frias & Nash, R. 2019). A commonly used description of microplastics is that they are smaller plastic particles under 5 mm in size. In 2016, EFSA (the European Food Safety Authority) reported that microplastics are heterogeneous mixtures of diverse forms (like spheres, fragments, and fibres) of materials. Therefore, microplastics are a transitory form between macrodebris and nanoparticles (Hale et al., 2020). Microplastics can be categorized into two classes: primary microplastics and secondary microplastics. Primary microplastics are tiny particles, including microbeads, exclusively designed for industrial and domestic uses. Secondary microplastics are derived from the breakdown or degradation of larger plastic items. This fragmentation is caused by atmospheric factors.

Sources of microplastics:

The presence of microplastics in aquatic environments has become an emerging concern globally. Microplastics in aquatic bodies originate from different sources. Around 80–90% of microplastics are released into the water bodies from land-based sources (Duis and Coors 2016). Therefore, a major share of microplastics is released into the ocean through rivers (Lebreton et al. 2017). Furthermore, in 2017, the International Union for Conservation of Nature (IUCN) divided the sources of marine microplastics into seven different categories: 1) synthetic textiles; 2) vehicle tires; 3) road markings; 4) city dust; 5) personal care products and cosmetics; 6) marine coatings; and 7) plastic pellets. IUCN (2017) also states that synthetic textiles are responsible for the release of 35% of primary microplastics into the global marine environment every year. IUCN (2017) also estimates that 28% of the annual total primary microplastics enter the oceans from the abrasion of automotive tires. Personal care products and cosmetics are also prime sources of microplastics entering the marine environment. Microbeads, polyethylene, and polyurethane are used in personal care or cosmetics as additives, viscosity controllers, stabilizers, thickeners, colors, binders for powders, bulking agents, and dispersant agents (Lassen et al. 2015; Scudo 2017). It contributes around 2% of total primary microplastics released into the marine environment (IUCN 2017). Whereas road markings and plastic pellets contribute 7% and 0.3% of primary microplastics in marine environments annually (IUCN 2017). City dust refers to artificial turf, abrasion of objects, building paint, and industrial blasting of abrasives originating from urban areas, sharing 24% of total primary microplastics that are released into marine ecosystems (Sundt, Schulze, and Syversen 2014; IUCN 2017). The paints applied to commercial ships contain polymers that act as binding agents in marine coatings (Tamburri et al., 2022). It makes up 3.7% of total marine primary microplastic pollution.

In addition, secondary microplastics enter the water bodies in macro-size, breaking down into microplastics under water. The major sources of secondary microplastics are mainly terrestrial macro-sized refuse and marine-based refuse (e.g., fishing gear, shipping waste, and losses) (https://www.firstsentier-mufg-sustainability.com/research/microplastics-05-2020.html).

Impact of microplastics on fish health:

MPs pollution is a growing environmental issue posing a great threat to fish health (Garrido Gamarro et al., 2020; Kutralam-Muniasamy et al., 2020; Huang et al., 2021; Aragaw and Mekonnen, 2021). Many studies have been reported about MPs, but a large portion of their consequences is unknown to us (Kutralam-Muniasamy et al., 2020). MPs affect every aquatic life, being fish among the most affected taxa. A large number of fish species suffer adversely due to the toxic effects of MPs (Mizraji et al., 2017; Fonte et al., 2016). The presence of microplastics has been detected in a large scale of edible fishlike mackerel (*Scomber scombrus*), blue whiting (*Micromesistius poutassou*), chub mackerel (*Scomber japonicus*), hake (*Merluccius merluccius*), sprat (*Sprattus sprattus*), etc. (Alberghini et al., 2022). MPs contamination was also observed in many migratory fish, like *Dicentrarchus labrax* (seasonal migratory fish) and *Thunnus thynnus* (migratory commercial fish) (Alberghini et al., 2022). Many studies have described the negative effects of microplastics on fish. Microplastics cause physical harm as they build up in the gastrointestinal tract of fish, causing hazards in their digestive system and feeding mechanism (Lusher et al., 2013; Wright et al., 2013). Ingestion of MPs could also induce clogging of the alimentary appendages, anatomical and functional changes in the digestive tracts, and inflammation leading to dietary and developmental issues in fish (Huang et al., 2022; Borrelle et al., 2017; Peda et al., 2016; Jabeen et al., 2018;). MPs are mainly stored in the gills, gut, and stomach within the fish body (Lu et al., 2018; Güven et al., 2017; Greven et al., 2016). MPs can cause behavioral alterations, such as affecting predatory behavior in fish and reducing the ability to differentiate between microplastics and genuine prey (de Sá et al., 2015). This harmful effect results in malnutrition in fish. Several studies have demonstrated the negative consequences of microplastics on the immune system of fish (Greven et al. 2016). Sometimes MP contamination can induce mortality (Mallik et al., 2021). *Danio rerio* was the most studied fish to show the impact of microplastics on fish health. The visible effects of MPs contamination in *Danio rerio* are damage to reproductive organs, disruption of gene expression and oxidative stress (Mu et al., 2021; Zhao et al., 2021;

Zhang et al., 2022). The second most studied fish is *Oryzias melastigma*, to know how ingestion of MPs causes physiological changes (Xia et al., 2022). The common effects of MPs ingestion in *Oryzias melastigma* are weight reduction, retardation or inhibition of growth, damage to the reproductive system, and liver dysfunction (Wang et al., 2022; Feng et al., 2021; Li et al., 2021; Le Bihanic et al., 2020). Sometimes, microplastics act as carriers for transferring additives, toxic chemicals, and metals from the environment to fish (Du, H., Xie, Y., & Wang, J., 2022). Monomers and additives of MPs disrupt endocrine function in fish (Kumar et al., 2020). In the case of freshwater fish, MP exposure levels are highly variable. It is typically based on the type, size, and shape of MPs. MPs contamination in freshwater fish is also associated with cell damage and altered morphology of physiological structures (Lu et al., 2016; Yu et al., 2020). Microplastics also act as a vector for various pathogens and invasive species (Caruso, 2019).

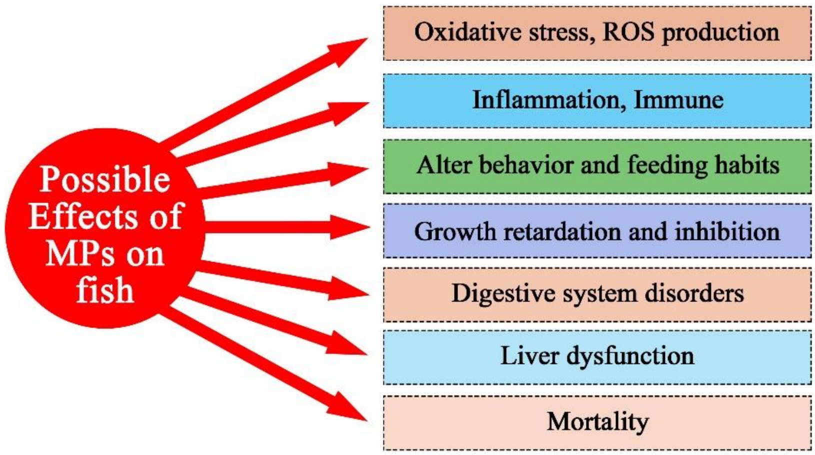

Figure 1. Possible Effects of Microplastics contamination in fish

Microplastics contamination in fish poses risks to human health:

Microplastics contamination in fish is a potential threat to human health, as fish or fishery products are one of the prime sources of contamination in the human diet. Generally, MPs enter the human body through endocytosis or persorption (Bhuyan, 2022). Biomagnification and trophic transfer have been seen in a wide variety of fish. Microplastics are biomagnified and transferred from fish to humans through the food-consumer relationship (Bhuyan, 2022). Recently, there has been a lot of research on microplastics around the world, but that is not enough; more research is required to understand this topic scientifically. *In vitro* tests revealed that MPs can be absorbed by macrophages, leading to cytotoxicity like oxidative damage and inflammation (Geiser et al., 2005; Yacobi et al., 2008). A small amount (0.05–10 mg/L) of MPs produces ROS (reactive oxygen species) at a large level, which results in cytotoxicity in the human brain and epithelial cells (Schirinzi et al., 2017). MPs also have toxicological consequences for human health, such as immune cell impairment and chronic discomfort (Smith et al., 2018). Accumulation of MPs at a high level in the human body can cause inflammatory bowel disease (Yan et al., 2021). MPs can change the human body's metabolism and energy flow. It alters the function of metabolic enzymes, disrupts energy equilibrium, and hampers nutritional intake (Bhuyan, 2022). MPs can also induce autoimmune disorders or immunosuppression (Prata, 2018; Prata et al., 2020). Within the human body, MPs transport from one tissue to another via the circulatory system. MPs build up in the cardiovascular system, leading to blood cell cytotoxicity, respiratory high blood pressure, vascular swelling, and inflammatory reactions (Wright and Kelly, 2017; Campanale et al., 2020). According to Hwang et al. (2019), MPs instigate hemolysis and the production of inflammatory molecules like histamine. MPs may increase the risk of neoplasia when transported to distal tissues (Prata et al., 2020). Persistent exposure to microplastics leads to neurotoxicity. MPs alter serum neurotransmitters and elevate AChE activity in the brain (Deng et al., 2017). In some cases, MPs cause prolonged inflammation and irritation that lead to cancer by damaging DNA (Prata, 2018). MPs also generate free radicals within the human body, causing cytolysis and agglomeration of unfolded protein particles in the endoplasmic reticulum (Chiu et al., 2015). Microplastics also transport a variety of microbes that are harmful to humans (Kirstein et al., 2016). Some chemical additives in MPs, like phthalates bisphenol-A, disrupt endocrine systems (Ludovic H et al., 2017).

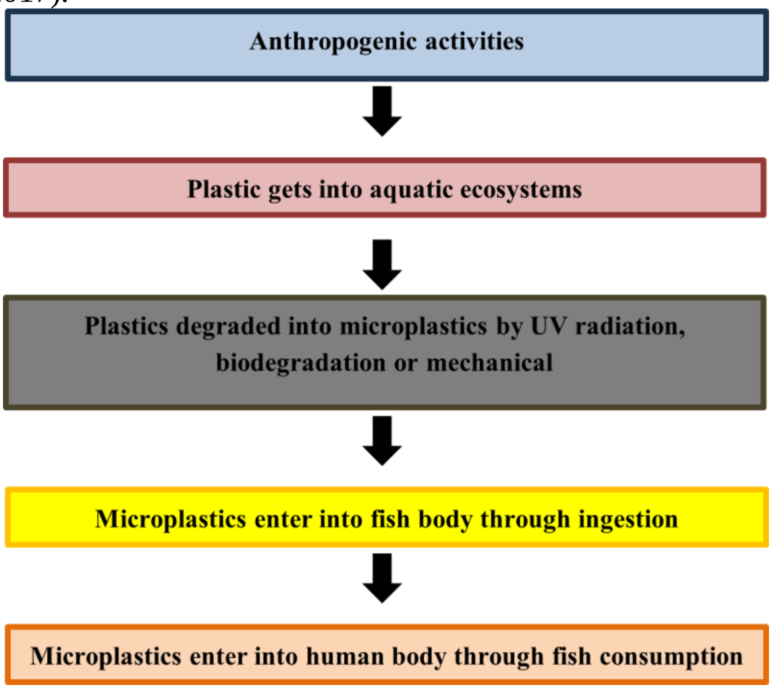

Figure 2. A model showing how microplastics make a path to human body

Discussion:

Both fish and humans are extremely vulnerable to microplastic pollution. Plastic production will continue to increase with the growth of the human population. Nevertheless, the lack of standard protocol and lack of public awareness made it an omnipotent issue. Nowadays, research is mainly focused on microplastics' impact on marine fish or other animals. Studies are required about the impact of microplastics on freshwater fish for a better understanding of this emerging concern. The contamination of microplastics in fish species used for human consumption is a burning issue. Yet, the transmission of microplastics from fish to the human body requires lots of studies to understand. Moreover, a handful of strategies are present to control this global issue. Strategies should focus on remediation technologies and the development of cost-effective ways to clean up microplastics. Research is going on microbial biodegradation and bioremediation of microplastics, which is a potential hope. Thus, there is a need for an immediate action plan and proper waste management to reduce microplastic pollution.

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Chapter- 11

Fish Diversity of the Titas River, Bangladesh: Present Status and Conservation Needs

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Keywords: Fish, diversity, Titas River, Conservation, Bangladesh

Abstract:

The transboundary river Titas, originating from India, follows through Bangladesh and shows a significant number of fish species throughout its journey. The current research identifies a collective of 64 species across 29 families. Among these, Cypriniformes emerged as the predominant order, with 22 species. The remaining, 16, 11, 4, 3, 2, 2, 2, 1, and 1 species were recorded from Perciformes, Siluriformes, Clupeiformes, Synbranchiformes, Osteoglossiformes, Beloniformes, Decapoda, Cichliformes, and Tetraodontiformes, respectively. Considering the status from IUCN Bangladesh 2015, among the total species, 9.38% were endangered, 10.94% were vulnerable, 12.50% were near threatened, 59.38% were least concerned, 6.25% were data-deficient, and 2.78% were not evaluated. The diversity index, richness index, and evenness index yielded values of 1.78790, 4.90816, and 0.42990, respectively. Analysis of the diversity and richness indices indicated that fish fauna diversity peaked during July (monsoon) and reached its lowest point in January (winter). Throughout the study duration, the proportion of rare fish species in the total catch, at 21.81%, underscores the site's considerable potential for natural conservation. The main reasons for the decreased diversity in the studied areas are brood fish catching and the usage of small mesh-sized nets during breeding season. This problem could be overcome by creating both permanent and temporary fish sanctuaries (during breeding seasons) and increasing awareness among fishery communities and consumers about the importance of the conservation of fish diversity.

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Introduction:

Bangladesh, endowed with extensive water resources, stands as one of the foremost fish-producing nations globally, achieving a total amount of 47.59 million metric tons in 2021-2022. Inland open water (capture) contributes 27.78 % to this production, securing a third-place ranking worldwide (DoF, 2022). Taking into account both capture and culture, the fisheries sector constitutes 2.08 % of the total national GDP and 21.83 % of the agricultural GDP, highlighting the significant reliance of the population on this sector as well (DoF, 2022). Presently, per capita fish consumption has reached 63 grams per day, surpassing the established target of 60 grams per day (DoF, 2022). Furthermore, this sector offers employment opportunities directly or indirectly to over 12% of the total population (DoF, 2022).

Conversely, the fisheries industry, particularly in open waters, encounters numerous challenges such as overexploitation, ecological shifts, and degradation of natural habitats, leading to the decline of many wild fish populations (Azadi and Alam, 2021). In its assessment, IUCN Bangladesh 2015 examined 253 freshwater fish species. This includes 9 species classified as critically endangered, 30 as endangered, 25 as vulnerable, and 27 as near threatened, while 122 were considered least concerned. Furthermore, 40 species were labeled as data-deficient freshwater fish species (IUCN Bangladesh, 2015).

Natural and artificial degradation of habitat was also noticed in Titas, a 98 kilometer transboundary river originating from Tripura State, India, that merges into the Meghna River, Bangladesh, and forms part of the Surma-Meghna river system (Ahmed and Akther, 2008). Titas river ecosystem is deteriorating due to reduced catch, inappropriate fishing gear, overfishing, conflicts over fishing areas, habitat degradation, and water pollution, leading to changes in fish abundance (Afrad et al., 2019).

For sustainable management of a water body, a detailed biodiversity study is necessary (Hossain et al., 2012). As a result, a survey was done in the Titas River (Nabinagar, Bokdhor-Urkhulia) from July to November, during the flooding seasons of 2002 and 2003. The study revealed that over 20% of the fish belonged to the Cypriniformes group (carps), including species such as *Labeo rohita, Puntius sarana, P. sophore*, and *Chirrhinus mrigala*. Approximately 15% were catfish (*Mystus aor*, *M. cavasius*, *Wallago attu*, etc.), 13% were pears, 60% were eels, and the remaining 46% consisted of small and medium-sized fish and prawns (Ahmed, 2008). In another study, it was found that Cypriniformes constituted the predominant order with 19 species, followed by Siluriformes with 12 species, Perciformes with 8 species, Synbranchiformes with 4 species, Channidiformes with 3 species, and Beloniformes with 1 species (Afrad et al., 2019).

While diversity index, richness index, and evenness index are crucial for evaluating and comparing diversity within an area, previous studies on the Titas River did not address these metrics. Therefore, the current study seeks to assess the fish species diversity in the Titas River, covering a larger stretch of 26 kilometers (from Urkhulia to Bitghar), and to provide recommendations for the conservation of vulnerable fish species. It is hoped that this study will prove beneficial for scholars, fishery managers, and policymakers, serving as a robust foundation for future research and initiatives.

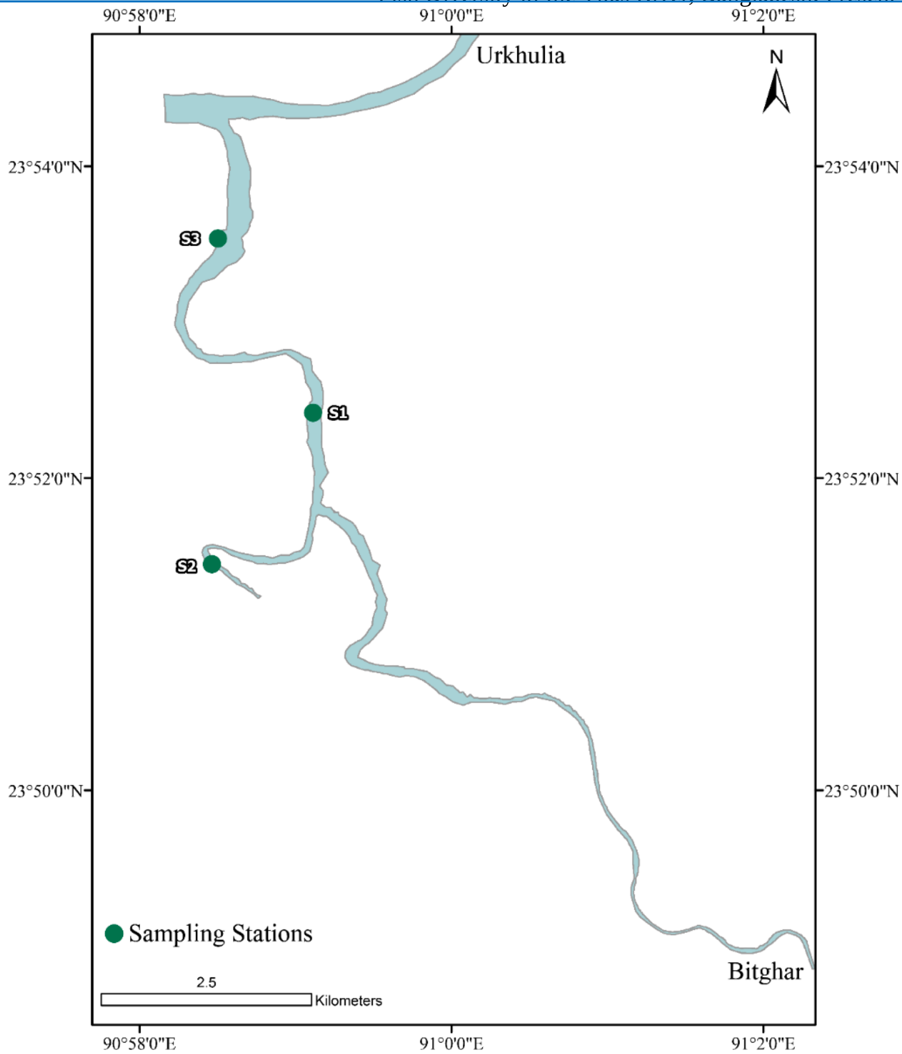

Figure 1. Map of Titas River

Materials and Methods

Study area

The survey was conducted from Bitghar (23°48'52.83"N, 91°1'11.62"E) to Urkhulia (23°54'48.08"N, 91°0'6.15"E), covering about 26 km. Within this area, samples were collected from three stations (Table 1 and Fig. 1), namely Kanikara (S_1), Bashbazar (S_2), and Khajanagar (S_3). All three stations were situated in Nabinagar upazila in Brahmanbaria district, Bangladesh.

Table 1: Study stations:

Sampling Station No.	Latitude	Longitude
S_1	23°52'25.28"N	90°59'6.78"E
S_2	23°51'26.97"N	90°58'27.87"E
S_3	23°53'32.34"N	90°58'30.09"E

The distance between S_1 and S_2 is 4 km, while S_1 and S_3 are 4.828 km and S_2 and S_3 are 8.828 km. In S_1, fish were collected from the area between Khajanagar and Bashbazar by the fisheries community. In S_2, fish were gathered from the river area between Khajanagar and Urkhulia. In S_3, fish were collected from the river area between Bashbazar and Bitghar. In order to conduct the survey, fish samples were collected from these three stations.

Sampling period

Samplings were done from May 2022 to April 2023 at the Titas River, covering all seasons over the course of a year. Samplings were made at each of the three stations (S_1, S_2, and S3) once a month.

Sample collection

Data and information were directly collected through field visits and observation at the sampling locations. Throughout the monthly sampling period, samples were obtained from the catch of selected fishermen of the local area as they fished at designated sampling sites. Throughout the research period, visits were made once per month. Various types of fishing gear, both non-selective (unspecified) and selective (specified), such as gill nets, set bag nets, seine nets, cast nets, lift nets, drag nets, traps, barriers, hooks, and lines, were utilized monthly to gather samples from selected stations along the Titas River. Photographs of the samples were captured, and their color patterns were observed in their fresh condition.

Data Analysis

Confirmations of identifications were made by examining the morphological characteristics (external features) of the samples, and regional threats were assessed using IUCN (2015). Species availability was determined through the analysis of catch assessment data. The classification system largely adhered to the framework outlined by Nelson et al., 2016. Following the guidelines and standards set forth in the international code by ICZN, the scientific names of all genera and species were listed, along with their known vernacular names. The global conservation status was assessed using the IUCN database from 2016, while the local conservation status was determined based on IUCN Bangladesh (2015).

Species assemblage and fish diversity analysis

This study calculated the Shannon-Weaver diversity index (H), Pielou's evenness index (e), and Margalef's richness index (D) to assess fish diversity status, employing the following formulas:

Shannon-Weaver diversity index,

$H = -\Sigma \, Pi \ln Pi$

In this context, H represents the diversity index, while Pi denotes the relative abundance (s/N)

Margalef's richness index,

$D = s-1/LnN$

In this context, s represents the number of individuals for each species, N denotes the total number of individuals, and D stands for the richness index

Pielou's Evenness index,

$e = H/LnS$

In this context, 'S' represents the total number of species, 'e' stands for the similarity or evenness index, 'ln' denotes the natural logarithm, and 'H' represents the diversity index.

Result

Fish Diversity of Titas River

Throughout the study period, a total of 375,403 individual fish were classified into 10 orders and 29 families. Among these, Cypriniformes emerged as the most abundant with 22 genera, followed by Perciformes with 16 genera (Table 2). The number of threatened fish species in the river was determined based on the total number of individuals, following the guidelines provided by IUCN Bangladesh (2015).

Table 2: Inventory of fish diversity in the Titas River and its present condition

S.N.	Order	Family	Scientific Name	Local Name	Availa-bility	Status in Bangla-desh	Global Status
1	Cypriniformes	Cyprinidae	*Amblypharyngodon mola*	Mola	ST	LC	LC
2			*Esomus danricus*	Darkina	ST	LC	LC
3			*Osteobrama cotio*	Dhela	OC	NT	LC
4			*Salmostoma argentea*	Chela	R	DD	LC
5			*Salmophasila bacila*	Katari	OC	LC	LC
6			*Catla catla*	Catla	DC	LC	NE
7			*Cirrhinus cirrhosus*	Mrigal	ST	NT	VU
8			*Gaiant danio*	Chebli	R	DD	LC
9			*Labeo ariza*	Bata	OC	VU	LC
10			*Labeo bata*	Batkhara or Bhagla	ST	LC	LC
11			*Labeo gonius*	Ghannia	OC	NT	LC
12			*Labeo calbasu*	Kalibaos	ST	LC	LC
13			*Labeo rohita*	Rui	DC	LC	LC
14			*Oreichthys cosuatis*	Titputi	ST	EN	LC
15			*Systomus sarana*	Sarputi	R	NT	LC
16			*Puntius terio*	Teri punti	ST	LC	LC
17			*Pethia ticto*	Tit punti	DC	VU	LC
18		Cobitidae	*Botia dario*	Betrangi	DC	EN	LC
19			*Lepidocephalichthys berdmorei*	Gutum	ST	LC	LC
20			*Canthophrys gongota*	Ghora gutum	R	NT	LC
21		Xenocyprididae	*Hypoptalmochthys molitrix*	Silver carp	DC	NT	LC
22		Xenocrypridae	*Ctenophyngodon idella*	Grass carp	DC	NE	NE
23		Gobidae	*Gobiopis macrostoma*	Baila	DC	DD	NE
24			*Parapocryptes batoides*	Chengbaila	R	LC	NE

25	Perciformes	Channidae	*Channa margulis*	Gajar	DC	EN	LC
26			*Channa punctatus*	Taki	ST	LC	LC
27			*Channa striatus*	Shol	OC	LC	LC
28		Ambassidae	*Pseudambassis ranga*	Gol chanda	ST	LC	LC
29			*Chanda nama*	Lamba chanda	LF	LC	LC
30			*Pseudambassia lata*	Lal chanda	LF	LC	NE
31		Polynemidae	*Polynemous paradiseus*	Taposi	R	LC	NE
32		Sciaenidae	*Otolithodes pama*	Poa	R	LC	NE
33		Nandidae	*Nandus nandus*	Meni	ST	NT	LC
34		Anabantidae	*Anabas testudineas*	Koi	LF	LC	DD
35		Osphronemidae	*Trochogaster fasciata*	Khalisha	OC	LC	LC
36			*Trichogaster chuna*	Chuna khalisha	OC	LC	LC
37			*Trichogaster lolius*	Lal Khalisha	DC	LC	LC
38		Pristolepidae	*Badis badis*	Napit koi	R	LC	NE
39	Siluriformes	Schilbediae	*Eutropiichthys vacha*	Bacha	DC	LC	LC
40			*Pseudeutropius*	Batasi	DC	LC	LC
41		Bagridae	*Mystus gulio*	Guillya	MDT	LC	LC
42			*Mystus vittatus*	Dora tengra	MDT	LC	LC
43			*Mystus tengara*	Bazari tengra	ST	LC	LC
44			*Sperata aor*	Air	R	VU	LC
45		Siluridae	*Ompok pabda*	Pabda	DC	EN	NT
46			*Wallago attu*	Boal	R	VU	NT
47		Schilbeidae	*Ailia punctata*	Kajuli	R	LC	NE
48		Clariidae	*Clarias batrachus*	Magur	R	LC	LC
49		Heteropneustes	*Heteropneustes fossilis*	Shing	DC	LC	LC
50	Clupeiformes	Clupeidae	*Corica soborna*	Kachki	DC	LC	LC
51			*Gudusia chapra*	Chapila	DC	VU	LC
52		Pritigasteridae	*Ilisha melastoma*	Khorchona	R	DD	NE
53		Engarulidae	*Setipinna taty*	Phaissa	LF	LC	NE
54	Synbranciformes	Mastacembelidae	*Macrognathus aculeatus*	Tara baim	MDT	NT	NE
55			*Macrognathus armatus*	Sal baim	ST	EN	NE
56			*Macrognathus panclus*	Guchi baim	MDT	LC	LC
57	Tetraodontiformes	Tetraodontidae	*Tetradon cutcutia*	Potka	ST	LC	LC
58	Beloniformes	Adrianchthyidae	*Oryzias melatogma*	Kanpona	DC	LC	LC
59		Hemiramphidae	*Hyporhamphus limbatus*	Kakia	ST	LC	LC
60	Osteoglossiformes	Notopteridae	*Chitala chitala*	Chitol	R	EN	NT
61			*Notopterus notopterus*	Canla	OC	VU	LC
62	Cichliformes	Cichlidae	*Oreochromis*	Tilapia	MDT	VU	NE

			mossambicus				
63	Decapoda	Palaemonidae	*Macrobrachium rude*	Kucha Chingri	ST	LC	LC
64			*Macrobrachium Rosenbergii*	Golda Chingri	LF	LC	LC

* The status categories DD, CR, EN, LC, and VU are derived from the IUCN Bangladesh, 2015); where DD stands for Data Deficient, CR for Critically Endangered, EN for Endangered, and LC for Least Concerned.

* ST= stable (>70 % individuals of species), MDT= moderate (31-70 % individuals of species), LF=less frequent (20-30% individuals of species), R = rare (0.01-5% individuals of species), OC= occasional (>10% individuals of species but found occasionally like lunar eclipse and tidal effect), DC= decreased (5-20% individuals of species).

Considering the regional status from IUCN Bangladesh 2015, Among the total 64 fish species of Titas River, 9.38% were endangered (6 species), 10.94% were vulnerable (7 species), 12.50% were near threatened (8 species), 59.38% were least concern (38 species) and 6.25% were data deficient (4 species), 2.78% not evaluated (1 species) based on the species diversity across various categories.

Characteristics of the different fish groups in terms of overall population and diversity:

During the study period, a collection of 64 species from 10 orders was documented in the Titas River. The relatively lower abundance of certain species across seven orders was notable, with Tetraodontiformes (1.56%), Cichliformes (1.56%), Beloniformes (3.13%), Osteoglossiformes (3.13%), Decapoda (3.13%), Clupeiformes (6.25%), and Synbranchiformes (4.69%) being particularly minor. Contrarily, the exorbitant species from the other three orders, Siluriformes (17.19%), Perciformes (25.00%), and Cypriniformes (34.38%), posed them as mammoth orders of the Titas River (Fig. 2).

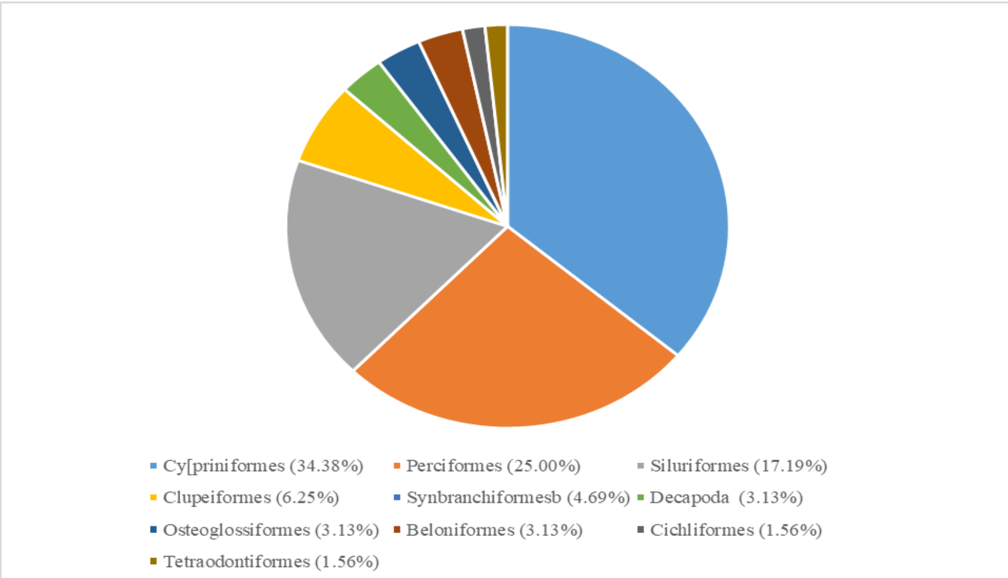

Figure 2. Percentage of fish species composition across various orders observed in the Titas River

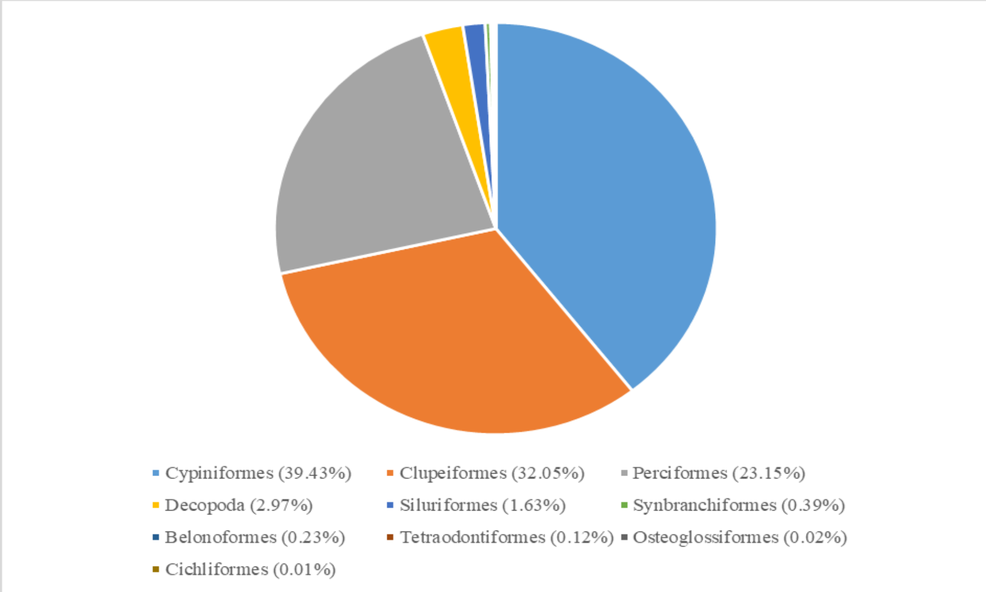

Figure 3. Percentage of fish species diversity across various orders observed in the Titas River

The pattern of diversity among species closely corresponded to their contribution to the overall richness of the order observed in this study. Among the total count of 375,403 individuals, only a minimal percentage of species diversity contributed to the formation of minor order richness. Specifically, this contribution amounted to 0.01% for Cichliformes, 0.02% for Osteoglossiformes, 0.12% for Tetraodontiformes, 0.23% for Beloniformes, 0.39% for Synbranchiformes, 1.63% for Siluriformes, and 2.97% for Decapoda. The majority of species (94.60%) encountered in the Titas River belonged to the other three predominant orders, namely Perciformes (23.15%), Clupeiformes (32.05%), and Cypriniformes (39.43%) (Fig. 3).

Threatened species identified within the study region

Based on data from IUCN Bangladesh in 2015, concerning species diversity across various groups, it was observed that 33.33% of Synbranchiformes, 27.27% of Siluriformes, 25% of Clupeiformes, 18.18% of Cypriniformes, and 6.25% of Perciformes fish species in the Titas River were identified as threatened (Fig. 4). 79.68% of fish species were available throughout the year.

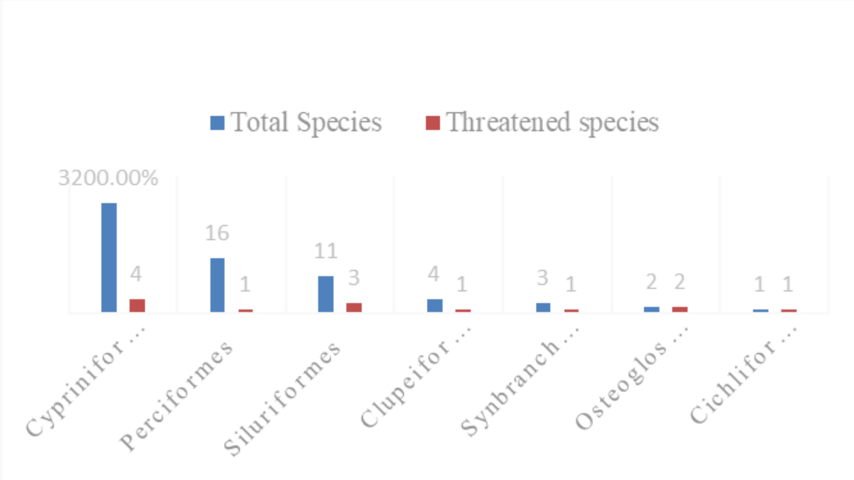

Figure 4. The count of threatened species across various orders detected in the study

Availability of fish species in the Titas River

In this study, 25% of fish species were found stable, 18.75% were considered rare, and the rest of the fish species were considered less frequent (7.81%), moderate (7.81%), occasional (17.19%), and decreased (23.44%) (Fig. 5). Among 64 species, 16 were stable, 12 were rare, 15 were decreased, 11 were occasional, 5 were moderate, and 5 were less frequent in the Titas River.

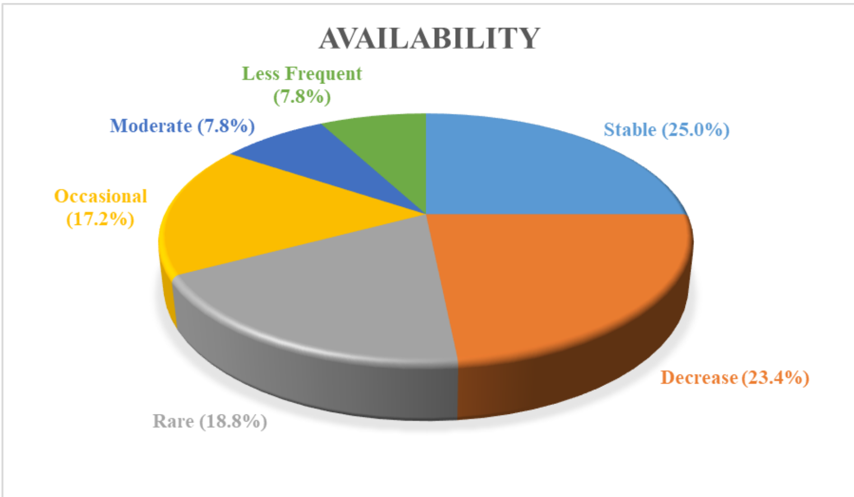

Fig. 5: Percentage of fish species availability in Titas River.

Diversity, richness and evenness indices of Titas River

Table 2 presents the monthly values of Shannon-Weaver diversity (H), Margalef's richness (D), and Pielou's evenness (e) indices. The Shannon-Weaver diversity index (H) typically falls within the range of 1.5 to 3.5, rarely extending to 4.5. A high 'H' value indicates a diverse and evenly distributed community, whereas lower values signify a less diverse community (Hossain et al., 2013). The Margalef's richness index has an unlimited range and exhibits a precise linear correlation with species richness (Gaines et al., 1999). Pielou's evenness (e) refers to the distribution of individuals among species within a given area, ranging from zero to one, with zero representing no evenness and one representing complete evenness (Shannon & Weaver, 1998). Changes in fluctuation diversity, the count of genera, and Shannon-Weaver diversity within the fish community have exhibited parallel patterns when the diversity index and species richness index are correlated with both the number of species and the number of individuals in each species, with equal contributions from each (Gamito, 2010). Across all samples examined in the current survey of the Titas River, the values of 'H', 'D', and 'e' were determined to be 1.78790, 5.08427, and 0.42990, respectively. However, taking into account all specimens examined throughout the study duration, the diversity index varied between 1.548 (in February) and 1.889 (in September), the richness index ranged from 2.821 (in January) to 4.631 (in July), and the evenness index fluctuated from 0.435 (in August) to 0.512 (in September) (Table 3). The values of 'H' and 'D' demonstrated that the diversity of fish fauna reached its peak in July (Monsoon), characterized by the highest recorded number of fish species during this time. In contrast, the lowest species diversity was noted in January (Winter) (Table 3).

Table 3: Shannon-Weaver diversity, Margalef's richness and Pielou's evenness indices in each sampling month of Titas River in 2022- 2023

Month	No. of species	No. of individuals	H	D	e
May	41	31954	1.86927	3.85652	0.50336
June	49	50492	1.81631	4.43230	0.46670
July	53	75210	1.80270	4.63126	0.45408
August	46	28545	1.66571	4.38629	0.43507
September	40	29091	1.88945	3.79445	0.51220
October	38	25374	1.61592	3.64837	0.44423
November	37	24751	1.63915	3.55850	0.45394
December	33	21567	1.62714	3.20676	0.46536
January	29	20453	1.60438	2.82091	0.47646
February	30	19542	1.54823	2.93513	0.50464
March	31	22545	1.63124	2.99304	0.47503
April	36	25879	1.63902	3.44448	0.46100
All	64	375403	1.78790	4.90816	0.42990

Discussion

Bangladesh boasts approximately 700 rivers, encompassing tributaries, yet there is limited research conducted on the fish diversity of smaller rivers. In this study, a total of 64 fish species were documented from the Titas River, a figure comparable to the fish species found in the Choto Jamuna River in Naogaon district (Galib et al., 2013) and of the Halda River of Chittagong (Alam et al., 2013), both of which had 63 fish species recorded. The river Titas has larger fish species number than that of the river Chitra (53 species) in Jessore district of Bangladesh (Ali et al., 2014) and lower fish species number than that of the river Padma (80 species) in Chapai Nawabganj district (Rahman et al., 2012).

In this study, Cypriniformes emerged as the most diverse fish group in terms of both species count and individual numbers, followed by Perciformes and Siluriformes. Comparable results have been documented in various other rivers in Bangladesh, including the Choto Jamuna (Galib et al., 2013), the Mahananda (Mohsin & Haque, 2009), and the Padma (Rahman et al., 2012) where order Cypriniformes emerged as the most varied group of fish in terms of both species and individual numbers, while the order Siluriformes ranked as the second most diverse order.

In another study on the Titas River conducted by Afrad et al. (2019), Cypriniformes stood out as the most prevalent order, comprising 19 species, demonstrating similarity with the current study. However, the current study showed 22 species of Cypriniformes. Additionally, there was also a dissimilarity in terms of the total number of species, with 55 observed in the previous study compared to 64 in the current one.

The diversity and richness indices indicated that fish fauna diversity was greatest in July compared to other months. The highest number of fish species was observed during the pre-monsoon, monsoon (from June 15th to August 16th), and post-monsoon periods. In the dry season, the upper stretches of the Titas River become depleted, except for certain pools. Following the onset of the monsoon (from July to November), this area floods, creating a floodplain (Akhter, 2008). This is because the water surface of the Titas River increased to its maximum due to sufficient rainfall this time, allowing fish to breed more effectively. However, in the Titas River, the evenness value ranges from 0.435 to 0.512, with an overall evenness value of 0.43. This suggests a moderate distribution of individuals across species in the Titas River throughout the year.

Recommendations

Municipal waste and Sewage treatment: Continuous and proper management of sanitary landfills and sewage treatment plants implemented by Nabinagar Pourashava and UGHP-III, LGED should be maintained to protect the Titas River and conserve fish diversity.

Prevention of river bank erosion: In order to prevent river bank erosion, illegal sand and soil extraction particularly for brick fields should be strictly maintained.

Development of an integrated fishery management plan: To safeguard endangered species and restore equilibrium of fish population of the Titas River, it’s imperative to embrace integrated fishery management strategies that engage all stakeholders. This entails prohibiting the catch of brood and juvenile fish, imposing limitations on destructive and non-selective fishing gears and designating fish sanctuaries in critical river zones.

Implementation of rules and regulations: To stop overfishing and other anthropogenic issues (destructive fishing gear, destruction of habitat, construction of dam, embankment, and siltation), proper rules and regulation should be implemented by the law enforcement authority.

Establishment of a trained fish community: It was observed that more than half of the fishermen had no formal training. In order to educate them about the value of fisheries variety, extension agents should work with NGOs and other rural development organizations.

Creation of alternative income sources: Government agencies should explore alternative income sources to complement the existing single source of revenue. This could involve providing marketing assistance, distributing fishing equipment, and designating specific fishing areas. Such initiatives would notably mitigate local fishing conflicts.

Conclusion

Although the Titas River is a transboundary river in Bangladesh, it holds great significance for the country's economy. Throughout the study period, a total of 64 species spanning 10 orders were identified, with 6 species classified as endangered and 7 as vulnerable. Cypriniformes displayed the highest species count, while both Cichliformes and Tetraodontiformes were represented by a single species each. The fish population in this river is declining steadily due to anthropogenic factors and some natural occurrences such as high drought-prone areas and shifting river routes. The high proportion of rare fish species (21.81%) in the overall catch suggests that the Titas River holds significant potential as a prime location for natural conservation efforts. This study will establish a foundation for crafting future conservation and management strategies aimed at preserving fish diversity in the Titas River.

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Chapter- 12

AI, Human Memory and the Ability of Self via Cognitive Development

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Keywords: Artificial Intelligence; Human Memory; cognitive development; Spiritualism

Abstract:

This paper delves into the intricate interplay between artificial intelligence (AI), human memory, and spiritual development, aiming to uncover their interconnectedness and potential synergies in enhancing cognitive understanding and personal growth. Firstly, it comprehensively explores the concept of human memory, including its definition, function, processes, and stages, while outlining a comprehensive design to elucidate its workings. Secondly, it examines the complex relationship between memory and intelligence, highlighting various cognitive processes and factors involved. Thirdly, it conducts a detailed analysis of the physiological mechanisms underlying human memory, with a focus on glucose metabolism, oxygen supply, and nutritional factors, supported by scientific evidence and examples. Furthermore, it explores the spiritual dimensions of human memory, investigating the source of the power that establishes spiritual connections within memory processes. Finally, it examines the interconnectedness between AI, human memory, and spiritual development, elucidating their interactions and potential synergies in fostering cognitive understanding and personal growth. The qualitative study used interviews and group discussions to explore human memory's complexity and its links with intelligence, physiology, spirituality, and AI. Fifty participants shared diverse insights, guiding discussions on memory and spirituality. The comprehensive exploration of human memory uncovers intricate processes and mechanisms. Spiritual power, often overlooked, shapes memory function, influencing cognitive development and emotional resilience. Integrating spiritual aspects enriches understanding, fostering self-discovery and alignment with higher selves.

Introduction:

Embarking on a comprehensive exploration of human memory, this research endeavors to unravel its multifaceted nature, encompassing its conceptualization, physiological mechanisms, cognitive processes, and spiritual dimensions. Memory stands as a cornerstone of cognition, shaping our understanding of the world and facilitating adaptive behavior. However, the relationship between

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memory and intelligence is intricate, involving various cognitive processes and factors that warrant detailed examination. Furthermore, the physiological mechanisms underlying memory function, particularly the role of glucose metabolism, oxygen supply, and nutritional factors, play a crucial role in memory formation and consolidation. Beyond its cognitive and physiological aspects, memory also holds spiritual significance, serving as a repository of experiences, emotions, and connections that contribute to personal growth and spiritual development. Additionally, exploring the interconnectedness between artificial intelligence, human memory, and spiritual development unveils potential synergies that could enhance cognitive understanding and foster individual and collective growth. By delving into these diverse dimensions of memory, this research aims to provide a comprehensive understanding of its workings and implications for human cognition and spirituality.

Objectives:

1. To understand the concept of human memory, including its definition, function, processes, and stages, and to create a comprehensive design outlining the workings and stages of human memory.
2. To find out the relationship between memory and intelligence is complex and multifaceted, involving various cognitive processes and factors.
3. To conduct a detailed analysis of the physiological mechanisms underlying human memory, particularly focusing on the role of glucose metabolism, oxygen supply, and nutritional factors in memory function.
4. To explore the spiritual dimensions of human memory and investigate the source of the power that establishes spiritual connections within memory processes.
5. To examine the interconnectedness between artificial intelligence (AI), human memory, and spiritual development, exploring their interactions, influences, and potential synergies in enhancing cognitive understanding and personal growth.

Methods and materials:

The qualitative study utilized semi-structured interviews and focus group discussions to explore the multifaceted nature of human memory and its connections with intelligence, physiology, spirituality, and artificial intelligence. Fifty participants, chosen through purposive sampling, contributed diverse perspectives on memory-related topics. Interview guides and discussion protocols were developed, guiding conversations on memory definitions, functions, and spiritual experiences. Thematic analysis of the qualitative data revealed recurring themes and patterns, shedding light on the complex interplay between memory, intelligence, physiology, spirituality, and AI. Ethical guidelines were strictly followed to ensure participant confidentiality, informed consent, and respect for autonomy throughout the study.

Comprehensive Exploration and Design of Human Memory: Understanding, Function, and Stages

Embarking on a journey to unravel the intricacies of human memory, this comprehensive exploration delves into its multifaceted nature, encompassing definition, function, processes, and stages. Memory serves as the cornerstone of cognition, enabling us to encode, store, and retrieve information vital for daily functioning and personal growth. Through this exploration, we aim to unravel the mechanisms underlying memory's workings and stages, shedding light on its profound significance in shaping human experience and understanding.

Definition of Human Memory:

Human memory refers to the cognitive process of encoding, storing, and retrieving information acquired through experiences or learning. According to Atkinson and Shiffrin's modal model of memory (1968), memory involves the flow of information through sensory memory, short-term memory, and long-term memory.

- **Dual Process Theory:** Human memory can be understood through the Dual Process Theory, which posits two main memory systems: explicit (declarative) memory and implicit (procedural) memory. Declarative memory refers to conscious, intentional recollection of facts and events, while procedural memory involves unconscious, automatic memory for skills and habits (Tulving, 1972).
- **Levels of Processing Theory:** Another influential theory in memory research is the Levels of Processing Theory proposed by Craik and Lockhart (1972). This theory suggests that memory depends on the depth of processing rather than the mere repetition of information. Information that is deeply processed, such as through semantic analysis (meaningful processing), is more likely to be remembered than information processed superficially, such as through structural or phonemic analysis.
- **Working Memory:** Working memory, as proposed by Baddeley and Hitch (1974), is a temporary storage system that allows for the manipulation and processing of information needed for complex cognitive tasks, such as problem-solving and comprehension. It consists of several components, including the central executive, phonological loop, and visuospatial sketchpad, which work together to maintain and manipulate information.
- **Episodic Memory vs. Semantic Memory:** (Tulving, 1972) distinguished between episodic memory, which involves the conscious recollection of specific events or experiences tied to a particular time and place, and semantic memory, which refers to general knowledge about the world, including facts, concepts, and meanings.
- **Memory Consolidation:** Memory consolidation is the process by which memories are stabilized and strengthened over time. It involves the transfer of information from short-term memory to long-term memory through processes such as rehearsal, elaboration, and sleep-dependent consolidation (McGaugh, 2000).
- These definitions and analyses provide a nuanced understanding of human memory, incorporating insights from various theoretical frameworks and empirical research.

Function of Human Memory:

Human memory serves as a crucial cognitive function, allowing individuals to retain and utilize past experiences, knowledge, and skills to adapt to present situations and plan for the future. It facilitates learning, problem-solving, decision-making, and various other cognitive processes essential for survival and functioning in society.

How human memory works, step by step:

i. **Encoding:** The process of encoding involves transforming sensory input into a form that can be stored in memory. This can occur through various mechanisms, such as visual, auditory, semantic, or motor encoding, depending on the nature of the information. For example, when learning a new concept, individuals may encode it visually by creating mental images, or semantically by relating it to existing knowledge.

ii. **Attention:** Attention plays a critical role in memory encoding by selecting and focusing on relevant sensory information while filtering out distractions. When attention is directed towards stimuli, it enhances the encoding process by increasing the likelihood that information will be stored in memory. For instance, actively listening to a lecture or concentrating on a task improves memory encoding compared to passive or distracted states.

iii. **Storage:** Once information is encoded, it is stored in memory for later retrieval. The storage phase involves maintaining encoded information over time, which can occur through various memory systems and structures in the brain. Information may be stored temporarily in short-term memory or more permanently in long-term memory. For example, short-term memory holds information briefly, such as remembering a phone number temporarily, while long-term memory stores information for extended periods, such as remembering significant life events.

iv. **Rehearsal:** Rehearsal involves actively maintaining and refreshing information in memory, which helps to transfer it from short-term memory to long-term memory. This process can occur through repetition or elaborative rehearsal, where individuals relate new information to existing knowledge or create meaningful connections. For instance, repeating a list of items or associating them with personal experiences enhances memory consolidation.

v. **Retrieval**: Retrieval is the process of accessing and bringing stored information into conscious awareness when needed. It involves reconstructing memories based on cues or triggers, which can be external (e.g., environmental cues) or internal (e.g., associations or emotions). Retrieval cues facilitate the retrieval process by activating associated memory traces. For example, when trying to recall a friend's name, seeing their face may serve as a retrieval cue that helps retrieve the associated name from memory.

vi. **Forgetting:** Forgetting is a natural part of the memory process and occurs when stored information becomes inaccessible or cannot be retrieved. It can result from various factors, including interference from other memories, decay over time, or inadequate encoding or retrieval cues. However, forgetting is not always permanent, as memories may still exist in storage but require the right cues for retrieval. For example, a forgotten password may be remembered when prompted with familiar context or hints.

By understanding and optimizing each step of the memory process—encoding, attention, storage, rehearsal, retrieval, and forgetting—individuals can improve their memory performance and enhance their ability to learn, remember, and navigate the world around them.

Processes of Human Memory: Memory processes include encoding, storage, and retrieval. Encoding involves converting sensory input into a form that can be stored in memory. Storage involves maintaining encoded information over time. Retrieval involves accessing stored information when needed. These processes can be influenced by factors such as attention, rehearsal, organization, and emotional significance.

Stages of Human Memory:

i. **Sensory Memory:** This stage briefly retains sensory information from the environment, such as visual (iconic) or auditory (echoic) stimuli. It has a large capacity but a short duration.Sensory memory is the first stage of memory processing, where sensory information from the environment is briefly retained before either being transferred to short-term memory or fading away. It involves the initial registration of sensory input from various modalities, such as vision, hearing, taste, smell, and touch.

- **Duration and Capacity:** Sensory memory has a large capacity to store a vast amount of sensory information simultaneously. However, it has a very brief duration, typically lasting only a fraction of a second to a few seconds. For example, iconic memory (visual sensory memory) can last for about 0.5 to 1 second, while echoic memory (auditory sensory memory) can last for several seconds.
- **Function**: The primary function of sensory memory is to briefly retain sensory information long enough for further processing. It serves as a buffer between the sensory input and higher-level cognitive processes, allowing the brain to select and prioritize relevant information for further attention and encoding.
- **Selective Attention:** Sensory memory is closely linked to selective attention, which determines which sensory inputs are attended to and processed further. Selective attention helps filter out irrelevant information and enhances the transfer of relevant information to short-term memory for further processing and storage.
- **Example**: An example of sensory memory in everyday life is the experience of seeing a sparkler on a dark night. The bright, fleeting trail left by the sparkler is temporarily stored in iconic memory, allowing the viewer to perceive its continuous movement despite the brief duration of each spark. Similarly, when someone speaks to you, the initial sound waves are briefly stored in echoic memory, allowing you to perceive the continuous flow of speech.

ii. **Short-Term Memory (STM):** STM temporarily holds information that is being actively processed. It has a limited capacity (around 7 ± 2 items) and a relatively short duration without rehearsal, typically lasting up to 20-30 seconds.Short-Term Memory (STM) is a component of the memory system responsible for temporarily holding and manipulating information that is actively being processed.

- **Limited Capacity:** STM has a limited capacity, often referred to as "Miller's Law," which suggests that the average person can hold about 7 (plus or minus 2) items in STM at once (Miller, 1956). This capacity can vary depending on factors such as the complexity of the information and individual differences.
- **Duration of STM:** STM has a relatively short duration without rehearsal. Information in STM typically lasts for about 20 to 30 seconds if not actively rehearsed or refreshed (Peterson & Peterson, 1959). This limitation underscores the temporary nature of STM and the importance of transferring information to long-term memory for more enduring retention.
- **Maintenance Rehearsal:** To prolong the duration of information in STM, individuals can engage in maintenance rehearsal, which involves repeating or rehearsing the information to keep it active in STM. This process helps prevent the rapid decay of information from STM and facilitates its transfer to long-term memory.
- **Role in Cognitive Processing:** STM plays a crucial role in various cognitive tasks, such as problem-solving, decision-making, comprehension, and reasoning. For example, when solving a math problem, individuals may temporarily hold intermediate results in STM while performing calculations.

- **Neurobiological Basis:** STM is associated with specific brain regions, including the prefrontal cortex and parietal cortex, which are involved in attention, executive functions, and short-term storage of information (Baddeley, 2003). Neuroimaging studies have provided insights into the neural mechanisms underlying STM processes.
- **Relation to Working Memory:** STM is closely related to the concept of working memory, as proposed by Baddeley and Hitch (1974). Working memory encompasses not only the temporary storage of information (STM) but also the manipulation and processing of that information for cognitive tasks.

Long-Term Memory (LTM): LTM stores information for long periods, potentially indefinitely. It has a vast capacity and can hold various types of information, including facts, skills, and personal experiences. LTM can be further divided into explicit (declarative) memory, which includes conscious memories of facts and events, and implicit (procedural) memory, which involves unconscious memories of skills and habits.

i. **Storage Duration and Capacity:** Long-Term Memory (LTM) is characterized by its ability to store information for extended periods, potentially indefinitely (Atkinson &Shiffrin, 1968). Unlike Short-Term Memory, which has a limited duration, LTM can retain information over the long term. This aspect of LTM's function is crucial for preserving a vast array of knowledge and experiences accumulated over a lifetime.

ii. **Types of Information:** LTM has a vast capacity and can hold various types of information, including:

- **Facts**: Declarative memory within LTM encompasses conscious memories of factual knowledge, such as historical dates, vocabulary words, or mathematical concepts (Squire, 2004).
- **Skills**: Procedural memory, a component of LTM, involves the unconscious recall of skills and habits, such as riding a bike, playing a musical instrument, or typing on a keyboard (Squire, 2004).
- **Personal Experiences:** LTM stores autobiographical memories, which are recollections of specific events and experiences from one's own life, such as graduation day, a family vacation, or a childhood birthday party (Conway, 2005).

iii. **Explicit (Declarative) Memory:** This type of memory involves conscious recollection of facts and events. It can be further divided into semantic memory, which stores general knowledge about the world, and episodic memory, which preserves personal experiences tied to specific times and places (Tulving, 1972).

iv. **Implicit (Procedural) Memory:** Implicit memory operates unconsciously and involves the retention of skills, habits, and associations without conscious awareness. Examples include riding a bike, tying shoelaces, or playing a musical instrument (Squire, 2004).

v. **Neurobiological Basis:** LTM formation and storage involve complex neural processes, including synaptic plasticity and changes in neural connectivity (Bliss &Collingridge, 1993). The hippocampus, a region of the brain associated with memory consolidation, plays a critical role in transferring information from short-term to long-term storage (Squire, 2004).

In summary, Long-Term Memory (LTM) is a critical component of human memory that stores information for extended periods, with a vast capacity to hold various types of knowledge and experiences. It encompasses both explicit (declarative) and implicit (procedural) memory systems, supported by distinct neurobiological mechanisms.

The relationship between memory and intelligence is complex and multifaceted, involving various cognitive processes and factors.

i. **Memory as a Component of Intelligence:** Memory is considered a fundamental component of intelligence because it enables individuals to acquire, retain, and utilize information effectively. For example, individuals with strong memory abilities may excel in tasks requiring knowledge acquisition, retention, and retrieval, which are essential aspects of intelligence.

ii. **Working Memory and Intelligence:** Working memory, a system responsible for temporarily holding and manipulating information, is closely linked to intelligence. Research suggests that individuals with higher working memory capacity tend to perform better on cognitive tasks requiring problem-solving, reasoning, and decision-making, which are key components of intelligence (Engle, 2002).

iii. **Long-Term Memory and Intelligence:** Long-term memory, which stores information over extended periods, also contributes to intelligence. Individuals with a rich store of factual knowledge and experiences may demonstrate higher levels of intelligence, as they can draw upon this information to make informed decisions, solve problems, and engage in complex cognitive tasks (Ericsson &Kintsch, 1995).

iv. **Memory Retrieval and Intelligence:** The ability to retrieve relevant information from memory is crucial for intelligence. Individuals who can efficiently access and apply previously learned information to novel situations demonstrate adaptive intelligence. Effective memory retrieval allows for the synthesis of existing knowledge and the generation of creative solutions to problems.

v. **Memory and Learning:** Memory and intelligence are closely intertwined with the learning process. Memory facilitates the encoding and retention of new information, which is essential for learning and intellectual growth. Conversely, learning experiences enrich memory stores, leading to cognitive development and potentially enhancing overall intelligence (Anderson &Reder, 1999).

vi. **Neurobiological Basis:** The relationship between memory and intelligence has a neurobiological basis, with overlapping brain regions involved in both processes. For example, the prefrontal cortex, hippocampus, and parietal cortex play critical roles in memory formation, working memory, and higher-order cognitive functions associated with intelligence (Baddeley, 2003).

After that, the relationship between memory and intelligence is intricate and reciprocal, with memory serving as a cornerstone of intelligence by facilitating knowledge acquisition, retention, retrieval, and learning. The efficient functioning of memory systems, including working memory and long-term memory, contributes to cognitive abilities such as problem-solving, reasoning, and decision-making, which are hallmarks of intelligence.

The physiological mechanisms underlying human memory:

Human memory is a complex cognitive process that relies on various physiological mechanisms to function effectively. Among these mechanisms, glucose metabolism, oxygen supply, and nutritional factors play crucial roles in supporting memory function. Glucose, derived from food, serves as the primary energy source for the brain, facilitating neuronal activity involved in memory encoding, storage, and retrieval. Oxygen, essential for aerobic cellular respiration, ensures the efficient delivery of energy to brain cells, thereby sustaining cognitive processes underlying memory. Nutritional factors, including vitamins, minerals, and antioxidants, influence cognitive health and memory function. Understanding the interplay between these physiological factors is essential for unraveling the intricate workings of human memory and optimizing cognitive performance. This introduction provides a glimpse into the multifaceted nature of memory processes and sets the stage for exploring the role of glucose metabolism, oxygen supply, and nutrition in memory function.

Glucose Metabolism and Memory Function: Glucose metabolism serves as the primary energy source for the brain's metabolic activities, crucial for sustaining memory processes like encoding, consolidation, and retrieval. Stable blood glucose levels are essential for optimal cognitive function and memory performance, with fluctuations potentially impairing attention, learning, and memory. Experimental studies, such as Benton and Owens (1993), demonstrate the immediate impact of glucose intake on memory performance, highlighting the importance of adequate glucose supply for efficient neuronal activity. This relationship between glucose availability and memory function has significant clinical implications, particularly in conditions like Alzheimer's disease and diabetes, where maintaining stable blood glucose levels may help mitigate cognitive decline and support memory function. Overall, understanding the link between glucose metabolism and memory underscores the critical role of energy substrates in cognitive processes and has implications for both normal brain function and pathological conditions affecting memory.

Oxygen Supply and Cognitive Performance: Adequate oxygen supply to the brain is crucial for sustaining cognitive function, including memory processes. Oxygen is required for aerobic cellular respiration, which generates ATP (adenosine triphosphate), the energy currency of cells, supporting neuronal activity underlying memory encoding, storage, and retrieval (Vogel &Schwabe, 2016). Evidence suggests that increased oxygen availability can enhance cognitive performance and memory consolidation (Walter, 2007). For instance, research by Prabhakar and Semenza (2012) demonstrated that intermittent hypoxia, a condition associated with reduced oxygen levels, impaired spatial memory in rodents.

Nutritional Factors and Cognitive Health: Beyond glucose and oxygen, other nutrients and dietary factors play a role in maintaining cognitive health and memory function. For example, omega-3 fatty acids found in fish oil have been linked to improved cognitive performance and reduced risk of cognitive decline (Yurko-Mauro, 2010). Similarly, antioxidants such as vitamin E and polyphenols found in fruits and vegetables have been associated with enhanced memory and neuroprotection (Miller, 2018).

Omega-3 Fatty Acids:

- **Function:** Omega-3 fatty acids, particularly EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid), are essential for brain health and cognitive function. They contribute to the structure and function of brain cell membranes and play a role in neurotransmitter signaling, synaptic plasticity, and inflammation regulation (Gómez-Pinilla, 2008).
- **Memory Enhancement:** Research suggests that omega-3 fatty acids are associated with improved memory performance and cognitive function. For example, a study by (Yurko-Mauro, 2010) found that supplementation with DHA-rich fish oil improved cognitive performance in older adults with mild memory complaints.

- **Neuroprotective Effects:** Omega-3 fatty acids have neuroprotective properties, reducing the risk of cognitive decline and age-related cognitive disorders such as Alzheimer's disease (Cederholm, 2013). Their anti-inflammatory and antioxidant effects help mitigate neuronal damage and promote brain health over the long term.

Antioxidants (Vitamin E) and Polyphenols:

- **Function:** Antioxidants such as vitamin E and polyphenols found in fruits and vegetables help neutralize free radicals and oxidative stress, which are implicated in age-related cognitive decline and neurodegenerative diseases (Joseph et al., 1998).
- **Memory Enhancement:** Studies have shown that diets rich in antioxidants are associated with enhanced memory performance and reduced cognitive decline. For example, (Miller, 2018) demonstrated that dietary supplementation with blueberry, a rich source of polyphenols, improved cognitive function in older adults.
- **Neuroprotective Effects:** Antioxidants exert neuroprotective effects by reducing oxidative damage to brain cells and supporting neuronal function and survival (Kumar, 2012). By scavenging free radicals and modulating cellular signaling pathways, antioxidants help preserve cognitive function and promote brain health.

In summary, the analysis highlights the critical roles of glucose metabolism, oxygen supply, and nutrition in supporting human memory function, with scientific evidence demonstrating their importance and potential impact on cognitive performance.

The spiritual dimensions of human memory and investigating the source of the power that establishes spiritual connections within memory processes:

Spiritual Dimensions of Human Memory:

The exploration of spiritual dimensions within human memory involves recognizing memory as more than just a cognitive function but also as a repository of experiences, emotions, and connections that contribute to one's spiritual growth and understanding of the self and the world. Memories of significant events, relationships, and moments of transcendence may evoke feelings of awe, gratitude, or reverence, which are central to spiritual experiences.

- **Memory as a Repository of Spiritual Experiences:** Human memory serves as a repository for storing not only factual information but also profound spiritual experiences. These experiences can include moments of connection with something greater than oneself, such as feelings of awe in nature, profound insights during meditation, or deep emotional connections with others. Such memories are imbued with a sense of significance and meaning that transcends ordinary cognition and contributes to one's spiritual growth and understanding.
- **Emotional and Transcendent Aspects of Memory:** Memories of significant events, relationships, and moments of transcendence evoke powerful emotions such as awe, gratitude, or reverence, which are central to spiritual experiences. For example, recalling a moment of spiritual insight or a profound connection with a loved one may elicit feelings of profound gratitude or a sense of connection to a higher power or universal consciousness. These emotional responses contribute to the spiritual richness of memory and its role in shaping one's worldview and sense of purpose.

- **Interconnectedness of Memory and Spirituality:** The exploration of spiritual dimensions within memory underscores the interconnectedness of memory processes with broader spiritual themes such as interconnectedness, meaning-making, and transcendence. Memories not only reflect individual experiences but also connect individuals to a larger tapestry of human history, culture, and collective consciousness. This interconnectedness fosters a sense of belonging and unity with something greater than oneself, contributing to spiritual well-being and a deeper understanding of the self and the world.
- **Integration of Spiritual Insights into Daily Life:** Engaging with the spiritual dimensions of memory involves not only reflecting on past experiences but also integrating spiritual insights into daily life. This integration may involve practices such as mindfulness, meditation, prayer, or acts of kindness and compassion that cultivate a deeper connection to oneself, others, and the divine. By consciously nurturing spiritual awareness and insight through memory processes, individuals can deepen their spiritual practice and enhance their overall sense of meaning, purpose, and fulfillment.

Source of Spiritual Power in Memory Processes:

The source of the spiritual power that underlies memory processes can be multifaceted and subjective, often drawing from individual beliefs, cultural traditions, and personal experiences. For some, the power may be attributed to a divine or higher consciousness that imbues memories with meaning, purpose, and guidance. Others may view the power as emanating from the interconnectedness of all beings or the collective wisdom of humanity's shared experiences.

- **Individual Beliefs and Cultural Traditions:** The spiritual power underlying memory processes often reflects individual beliefs and cultural traditions. For example, in religious traditions such as Christianity, Islam, or Buddhism, memory is often viewed as a gift from a higher power or as a mechanism through which divine guidance is communicated to individuals. Memories of sacred texts, rituals, or spiritual experiences are imbued with profound significance and serve as anchors for faith and identity.
- **Personal Experiences and Meaning-Making:** The source of spiritual power in memory processes can also stem from personal experiences that evoke feelings of transcendence, awe, or interconnectedness. These experiences may include moments of beauty in nature, acts of compassion, or encounters with the numinous or mysterious. Such experiences imbue memories with deep emotional and existential meaning, shaping one's spiritual worldview and sense of purpose.
- **Interconnectedness and Collective Wisdom:** Some individuals perceive the source of spiritual power in memory processes as emanating from the interconnectedness of all beings and the collective wisdom of humanity's shared experiences. Memories are seen as nodes within a vast network of human consciousness, where each recollection contributes to the collective tapestry of human existence. In this view, memory serves as a repository of collective knowledge, cultural heritage, and evolutionary wisdom passed down through generations.
- **Psychological and Neurobiological Perspectives:** From a psychological and neurobiological perspective, the source of spiritual power in memory processes may be interpreted as arising from the complex interplay of cognitive, emotional, and neural mechanisms underlying memory formation and consolidation. The brain's capacity to encode,

store, and retrieve memories is influenced by neurotransmitters, synaptic plasticity, and neural networks that modulate the salience and emotional valence of remembered experiences.

- **Integration of Spiritual Insights:** Engaging with the spiritual dimensions of memory involves integrating spiritual insights gleaned from memory experiences into one's worldview, values, and behaviors. This integration process may occur through practices such as mindfulness, meditation, prayer, or reflection, which facilitate deeper awareness and connection with the spiritual aspects of life. By actively engaging with and embodying spiritual principles embedded within memory processes, individuals may cultivate greater wisdom, compassion, and alignment with their higher selves.

Interplay between Memory and Spiritual Connections:

Memory serves as a bridge between the material and spiritual realms, facilitating the connection between past, present, and future experiences. Spiritual connections within memory processes may manifest through moments of insight, intuition, or synchronicity that transcend ordinary perception and reveal deeper truths about existence and interconnectedness.

- **Memory as a Bridge Between Realms:** Memory serves as a conduit that transcends the boundaries between the material and spiritual realms. It allows individuals to access and reflect upon past experiences, which can hold profound spiritual significance. Memories of meaningful encounters, transformative moments, or instances of awe and wonder serve as points of connection between the tangible world and the realm of the unseen.
- **Facilitating Connection Across Time:** Memory enables individuals to bridge temporal gaps and connect with experiences from the past, present, and future. This temporal continuity provides a framework for understanding the unfolding of spiritual insights and revelations across different stages of life. For example, memories of past challenges overcome, or moments of spiritual awakening can inform and guide present actions and decisions, contributing to ongoing spiritual growth and development.
- **Manifestation of Spiritual Connections:** Spiritual connections within memory processes may manifest in various ways, such as moments of insight, intuition, or synchronicity. These experiences often transcend ordinary perception and reveal deeper truths about existence and interconnectedness. For instance, individuals may experience a sense of déjà vu, where past memories seem to align with present circumstances in a meaningful and synchronistic manner, suggesting a deeper underlying connection or purpose.
- **Uncovering Deeper Truths**: Memory serves as a repository of wisdom and insight, containing encoded knowledge and experiences that hold deeper truths about existence and interconnectedness. Through reflection and introspection, individuals can uncover these hidden truths within their memories, gaining a deeper understanding of themselves, their relationships, and the world around them. Spiritual connections within memory processes facilitate the exploration of existential questions and the pursuit of meaning and purpose in life.
- **Enhancing Spiritual Awareness and Growth**: Engaging with the spiritual dimensions of memory can enhance spiritual awareness and facilitate personal growth and transformation. By recognizing and honoring the spiritual significance of their memories, individuals can cultivate a deeper sense of connection with themselves, others, and the divine. This heightened

spiritual awareness fosters a sense of purpose, meaning, and fulfillment, guiding individuals on their spiritual journey towards greater wholeness and enlightenment.

Role of Reflection and Contemplation:

Exploring spiritual dimensions within memory often involves practices such as reflection, contemplation, and meditation, which allow individuals to access deeper layers of meaning and insight encoded within their memories. Through introspective inquiry, individuals may uncover hidden patterns, themes, or lessons that resonate with their spiritual beliefs and values.

- **Reflective Practices:** Reflection involves deliberately revisiting past experiences, memories, or emotions with the intention of gaining deeper understanding, insight, or meaning. Through reflective practices, individuals engage in a process of self-inquiry that allows them to examine their memories from different perspectives and discern underlying patterns or themes that may hold spiritual significance.
- **Contemplative Inquiry:** Contemplation refers to a state of focused attention and deep reflection, often facilitated through meditation, prayer, or mindfulness practices. Contemplative inquiry encourages individuals to approach their memories with openness, curiosity, and receptivity, allowing them to discern subtle nuances, insights, or revelations that may arise from within their consciousness.
- **Accessing Deeper Layers of Meaning:** Reflection and contemplation enable individuals to access deeper layers of meaning encoded within their memories, beyond surface-level recollection or factual information. By cultivating a contemplative mindset, individuals can tap into intuitive insights, symbolic associations, and emotional resonances embedded within their memories, leading to profound spiritual discoveries and revelations.
- **Uncovering Spiritual Themes and Lessons:** Through introspective inquiry, individuals may uncover hidden spiritual themes, lessons, or archetypal patterns that permeate their memories. These themes may relate to concepts such as interconnectedness, compassion, forgiveness, gratitude, or the search for meaning and purpose in life. By recognizing and reflecting on these spiritual motifs within their memories, individuals can gain deeper insights into their spiritual beliefs, values, and aspirations.
- **Integration with Spiritual Beliefs and Values:** Reflection and contemplation facilitate the integration of spiritual insights gleaned from memory experiences with one's core beliefs, values, and worldview. As individuals engage in reflective practices, they may discern how their memories align with or challenge their spiritual perspectives, leading to a deeper understanding of their spiritual journey and the interconnectedness of all aspects of life.
- **Enhancing Spiritual Growth and Transformation:** By engaging in reflective practices that explore the spiritual dimensions of memory, individuals can catalyze profound spiritual growth and transformation. Through the process of self-inquiry and contemplative exploration, individuals cultivate greater self-awareness, wisdom, compassion, and inner peace, fostering a deeper connection with themselves, others, and the divine or transcendent aspects of existence.

i. **Cultivating Spiritual Practices to Enhance Memory:**

Incorporating spiritual practices such as mindfulness, prayer, ritual, and gratitude into daily life can enhance memory function by promoting relaxation, focus, and receptivity to spiritual insights.

These practices create conducive conditions for accessing and integrating spiritual wisdom embedded within memory processes.

- **Mindfulness:** Mindfulness practices involve intentionally paying attention to the present moment without judgment. Research suggests that mindfulness meditation can improve attentional control and working memory capacity, leading to enhanced cognitive performance (Tang, 2007). By training individuals to be more present and focused, mindfulness can reduce distractions and enhance encoding and retrieval processes in memory.
- **Prayer**: Prayer is a spiritual practice that involves communication with a higher power or divine presence. Engaging in prayer can promote feelings of peace, gratitude, and connectedness, which have been associated with improved emotional well-being and cognitive function (Koenig, 2001). By fostering a sense of purpose and meaning, prayer may enhance memory by reducing stress and enhancing mood, both of which are conducive to optimal cognitive functioning.
- **Ritual**: Rituals are symbolic actions or ceremonies performed in a prescribed manner. Research suggests that engaging in rituals can increase feelings of control, reduce anxiety, and enhance social cohesion (Norton, 2012). Rituals associated with memory, such as commemorating significant life events or honoring ancestors, can serve as mnemonic devices that reinforce the encoding and retrieval of autobiographical memories.
- **Gratitude**: Gratitude practices involve expressing appreciation for the blessings and positive experiences in one's life. Studies have shown that cultivating gratitude can improve psychological well-being, increase resilience to stress, and enhance interpersonal relationships (Emmons & McCullough, 2003). Gratitude may also enhance memory function by promoting a positive mood state, which has been linked to improved cognitive performance and memory consolidation.
- **Neurological Mechanisms:** The beneficial effects of spiritual practices on memory function may be mediated by neurological mechanisms, including changes in brain structure and function associated with stress reduction, emotion regulation, and enhanced attentional control (Davidson, 2003). For example, mindfulness meditation has been shown to increase gray matter density in brain regions involved in attention, memory, and emotional regulation (Hölzel, 2011), potentially enhancing memory-related processes.

In summary, exploring the spiritual dimensions of human memory involves recognizing memory as a sacred and transformative aspect of human experience, with the power to deepen our understanding of spirituality, interconnectedness, and the nature of existence.

The interconnectedness between artificial intelligence (AI), human memory, and spiritual development:

Interconnectedness between AI and Human Memory:

AI Mimicking Human Cognitive Processes:

- Machine learning algorithms, a subset of AI technologies, are designed to process and analyze data to make predictions and decisions, mirroring certain aspects of human cognitive processes (Deng, 2014).

- In the context of memory, AI algorithms can be trained on large datasets to recognize patterns, associations, and correlations, similar to how humans encode and retrieve memories based on past experiences and knowledge.

Human Memory as Training Data for AI:

- Human memory plays a crucial role in training AI systems by providing labeled data for supervised learning tasks, such as image recognition or language processing (Clark, 2016).
- For example, when training a machine learning model to classify images, human-labeled images serve as training data to teach the algorithm how to distinguish between different objects or categories, analogous to how humans learn to categorize and recall visual information.

Augmentation of Human Memory by AI:

- AI technologies can augment human memory through the development of digital assistants and memory aids that assist with information retrieval, organization, and recall (Clark, 2016).
- Digital assistants, such as virtual personal assistants or smart home devices, leverage AI algorithms to process and respond to user queries, reminders, and requests, offloading cognitive tasks and enhancing memory function.

Integration of AI with Human Memory Systems:

- The integration of AI with human memory systems holds promise for enhancing memory function in individuals with cognitive impairments or neurological disorders (Berger, 2011).
- Neural prostheses and brain-computer interfaces (BCIs) are examples of AI-enabled technologies that interface directly with the brain to restore or enhance memory function in individuals with conditions such as Alzheimer's disease or traumatic brain injury.

Influences of AI on Spiritual Development:

- AI technologies have the potential to impact spiritual development by offering new tools and resources for spiritual exploration, such as virtual reality environments for meditation and mindfulness practices (Ahmed, 2019).
- However, concerns have been raised about the potential dehumanizing effects of AI on spirituality, such as the erosion of human connections and the commodification of spiritual experiences through algorithmic personalization (Brahms, 2020).
- Ethical considerations surrounding the development and use of AI in spiritual contexts, including issues of privacy, autonomy, and cultural sensitivity, must be carefully addressed to ensure that AI technologies support rather than hinder spiritual growth (Peters, 2018).

Influences of spirituality on AI:

i. Ethical Framework and Values:

- Spirituality often emphasizes ethical principles such as compassion, empathy, and respect for all beings. These values can influence the development of AI systems by encouraging researchers and developers to prioritize ethical considerations and human well-being in their work (Floridi, 2018).

- By integrating spiritual values into AI ethics frameworks, such as fairness, transparency, and accountability, developers can ensure that AI technologies align with moral and ethical principles.

Human-Centered Design:

- Spiritual teachings emphasize the importance of understanding human needs, emotions, and aspirations. Integrating spiritual insights into AI design processes can result in technologies that are more intuitive, empathetic, and responsive to human concerns (Brajnik, 2019).
- By adopting principles of human-centered design, AI systems can better address the holistic needs of users and foster trust, engagement, and acceptance.

Wisdom and Insight:

- Spirituality often fosters qualities such as wisdom, insight, and intuition, which can inform decision-making processes in AI development and deployment.
- Drawing on spiritual wisdom, AI researchers and practitioners can adopt holistic perspectives, consider long-term consequences, and anticipate potential ethical dilemmas or unintended consequences of AI technologies (Dignum, 2019).

Social Responsibility and Altruism:

- Spirituality encourages individuals to act with compassion, kindness, and altruism toward others. AI technologies can be harnessed to address social and environmental challenges, such as poverty, inequality, and environmental degradation, by facilitating data-driven decision-making and resource allocation (Hagendorff, 2019).
- By incorporating spiritual values into AI applications, researchers can promote social responsibility and collective well-being, fostering a more equitable and sustainable society.

Cultural Sensitivity and Inclusivity:

- Spirituality promotes respect for diverse cultural traditions, beliefs, and worldviews. AI systems should be designed to accommodate diverse perspectives, languages, and cultural norms, avoiding bias, discrimination, and exclusionary practices that may perpetuate social inequalities (Powell, 2019).
- By incorporating spiritual principles of inclusivity and cultural sensitivity into AI design and development, researchers can create technologies that reflect and respect the diversity of human experiences and identities.

Spirituality influences AI by shaping ethical frameworks, human-centered design practices, wisdom and insight, social responsibility, and cultural inclusivity. By integrating spiritual values into AI development processes, researchers and practitioners can create technologies that prioritize human well-being, foster empathy and compassion, and contribute to a more equitable and sustainable future.

Synergies in Enhancing Cognitive Understanding and Personal Growth:

Holistic Approach to Personal Growth:

- The integration of AI, human memory, and spiritual development allows for a holistic approach to personal growth, addressing cognitive, emotional, and spiritual dimensions simultaneously.
- By leveraging AI-driven technologies, individuals can access personalized learning experiences that draw insights from both human memory and spiritual practices, facilitating comprehensive cognitive development and self-discovery.

Enhanced Learning and Self-Reflection:

- AI-driven personalized learning platforms can tailor educational content and experiences based on individual preferences, learning styles, and past experiences stored in human memory.
- Integrating AI tools with spiritual practices such as meditation, reflection, and contemplation enables individuals to deepen their understanding of themselves and the world by providing personalized feedback, guidance, and insights.

Promotion of Mindfulness and Awareness:

- AI technologies can support the cultivation of mindfulness and self-awareness by providing real-time feedback on cognitive processes, emotional states, and behavioral patterns.
- By integrating AI tools with mindfulness practices, individuals can develop greater awareness of their thoughts, feelings, and behaviors, leading to enhanced cognitive understanding, emotional intelligence, and personal growth.

Facilitation of Personalized Spiritual Journeys:

- AI-driven platforms can assist individuals in navigating their spiritual journeys by offering personalized recommendations, resources, and support based on their unique interests, beliefs, and experiences.
- By integrating AI technologies with spiritual practices such as prayer, meditation, and sacred rituals, individuals can deepen their spiritual connection and foster inner transformation and well-being.

Ethical Considerations and Human Values:

- It is essential to consider ethical implications and human values in the development and use of AI technologies for personal growth and spiritual development.
- Developers and practitioners should prioritize principles of transparency, fairness, privacy, and respect for autonomy to ensure that AI-driven interventions uphold human dignity and promote holistic well-being.

Conclusions:

As per objective number one, in delving into the depths of human memory, we've uncovered its intricate processes, from the fleeting impressions of sensory memory to the enduring repository of long-term memory. Yet, amidst these scientific insights lies a profound dimension often overlooked: the role of spiritual power in shaping memory. While our exploration has focused on cognitive theories and neurobiological mechanisms, the essence of spiritual influence cannot be disregarded. Spiritual practices such as mindfulness, meditation, and gratitude have been shown to enhance memory function by fostering inner peace, clarity, and connection to a higher consciousness. Therefore, integrating spiritual principles into memory enhancement techniques offers a holistic approach to nurturing not only cognitive faculties but also spiritual well-being. As we continue to unravel the mysteries of human memory, let us not overlook the transformative power of the spiritual realm in enriching our understanding and experience of memory.

Based on objective number two, conclusively, while the exploration of memory and intelligence unveils their intricate interplay within cognitive processes, delving into the depths of spiritual power adds a nuanced dimension to this relationship. Spiritual power, often overlooked in traditional cognitive frameworks, can influence memory and intelligence through its capacity to foster inner growth, emotional resilience, and transcendent understanding. By cultivating spiritual practices such as mindfulness, prayer, and gratitude, individuals may tap into a reservoir of wisdom and insight that enhances memory function, supports cognitive development, and nurtures holistic intelligence. Thus, integrating spiritual power into the discourse on memory and intelligence enriches our understanding of human cognition and underscores the profound interconnections between mind, spirit, and intellect.

In conclusion of 3rd objective are, while the analysis has provided valuable insights into the physiological mechanisms underlying human memory, it's essential to acknowledge the potential influence of spiritual power on memory function. Spirituality encompasses beliefs, practices, and experiences that transcend the material realm, often guiding individuals towards deeper understanding, connection, and purpose. While the physiological aspects of memory are crucial, the role of spiritual power in memory function cannot be overlooked. Spiritual practices such as meditation, prayer, and mindfulness have been shown to enhance cognitive function, emotional well-being, and overall quality of life. By nurturing spiritual well-being alongside physiological health, individuals may unlock the full potential of their memory capacity, tapping into a source of inner strength, resilience, and wisdom that transcends the limitations of the physical world. Thus, integrating spiritual practices and principles into memory enhancement strategies may offer a holistic approach to optimizing cognitive performance and fostering personal growth.

Fourthly objective concluded that, delving into the spiritual dimensions of human memory unveils its profound significance as a conduit for transcendent experiences, emotional connections, and spiritual growth. Memories serve as repositories of sacred moments, profound insights, and existential truths, fostering a deeper understanding of spirituality, interconnectedness, and the human condition. The source of spiritual power within memory processes emanates from individual beliefs, cultural traditions, and personal experiences, enriching our spiritual journey with meaning, purpose, and wisdom. By engaging in reflective practices and integrating spiritual insights into daily life, we can harness the transformative potential of memory to cultivate greater awareness, compassion, and alignment with our higher selves, fostering spiritual growth and enlightenment. Ultimately, the exploration of memory's spiritual dimensions invites us to embark on a journey of self-discovery, connection, and transcendence, illuminating the path towards wholeness and spiritual fulfillment.

Finally, delving into the spiritual dimensions of human memory unveils memory's profound role as a conduit for spiritual experiences, insights, and connections. The recognition of memory as a repository of spiritual experiences underscores its significance in shaping one's spiritual growth, understanding of interconnectedness, and sense of purpose in life. Acknowledging the source of spiritual power within memory processes highlights the multifaceted and subjective nature of spirituality, drawing from individual beliefs, cultural traditions, personal experiences, and neurobiological mechanisms. Through reflection, contemplation, and integration of spiritual insights into daily life, individuals can harness the spiritual power inherent in memory to cultivate greater wisdom, compassion, and alignment with their higher selves. Ultimately, the exploration of memory's spiritual dimensions enriches our journey of self-discovery, fostering a deeper connection with ourselves, others, and the divine or transcendent aspects of existence.

Findings:

In the context of the overall discussion, the findings has to be reached that, the comprehensive exploration of human memory has unveiled its intricate processes and mechanisms, ranging from sensory impressions to long-term storage. While cognitive theories and neurobiological mechanisms provide valuable insights, the role of spiritual power emerges as a significant yet often overlooked dimension in shaping memory function. Spiritual practices like mindfulness and meditation have been shown to enhance memory by fostering inner peace and connection to higher consciousness. Integrating spiritual principles into memory enhancement techniques offers a holistic approach to nurturing cognitive faculties and spiritual well-being. Spiritual power adds a nuanced dimension to the relationship between memory and intelligence, influencing cognitive development and emotional resilience. Thus, acknowledging and integrating spiritual aspects into the discourse on memory enriches our understanding of human cognition and underscores the interconnectedness between mind, spirit, and intellect. Ultimately, exploring memory's spiritual dimensions invites us on a journey of self-discovery and transcendence, fostering greater awareness, compassion, and alignment with our higher selves.

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Chapter- 13

Evaluation of Biochemical Changes of Benzo (A) Pyrene Induced Lung Carcinogenesis in Vivo and its Prevention by Vesicular Drug Targeting

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Keywords: Benzo(a)pyrene, ROS, Biochemical changes, lung carcinogenesis, prevention by liposomal Curcumin

Abstract:

Lung cancer is the leading cause of cancer mortality world-wide. Cigarette smoking is the most established risk factor for lung carcinogenesis; however, the effects of benzo (a) pyrene [B(a)P], one of the key carcinogens in smoke, on the progression of lung cancer are obscure. The identification of key regulatory and molecular mechanisms involved in lung carcinogenesis is, therefore, critical to understanding this disease and could ultimately lead to targeted therapies to improve prevention and treatment. In an earlier study, I observed the effect of curcumin on the changes in the activities of endogenous antioxidants and lipohydroperoxide in rat lung injury by the administration of B(a)P. In the present study, I am interested in investigating whether B(a)P produces ROS, which activates inflammatory mediators and Wnt/β-catenin signaling to produce a lot of transcriptional genes and biochemical changes involved in lung carcinogenesis and its mechanistic prevention by the targeting of liposomal curcumin in rat.

Introduction:

The incidence of lung cancer is strongly correlated with cigarette smoking, with about 90% of lung cancers arising as a result of tobacco use (Biesalski et al., 1998; Peto et al., 2006; Maiti & Samanta, 2018; Dey & Guha, 2020). It is the single best-documented risk factor for all lung cancer types (Wynder et al., 1994). Each cigarette contains a mixture of carcinogens, including the tobacco-specific nitrosamine NNK and polycyclic aromatic hydrocarbons (PAHs) such as benzo(a)pyrene (B(a)P), among others, along with tumor promoters and co-carcinogens (Hoffmann et al.,1997; Hoffmann et al., 1990; Boga & Bisgin, 2022). The complex of PAHs and the tobacco-specific nitrosamine NNK in cigarette smoke is the mixture that is most likely to be involved in the induction of human lung cancer (Saha & Yadav, 2023; Mehta et al., 2023). Passive smoking, or the inhalation of tobacco smoke from other smokers sharing living or working quarters, is also an established development of lung cancer.

In my previous study, ROS were generated in BEAS-2B cells exposed by metals and induced and activated inflammatory mediators, Wnt/β-catenin signal transduction pathway, the key molecules responsible for carcinogenesis. Whether the same role of B(a) P-induced key

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factors may happen in lung carcinogenesis and inhibition of it on the basis of the mechanism of drug action will be examined.

Oxidative stress refers to the phenomenon of the production of ROS, namely superoxide (O_2), hydroxyl (OH) and peroxyl (ROO) radicals and hydrogen peroxide (H_2O_2), which exert a threat to lung cells. Lung cells, when exposed to ROS, trigger their self-antioxidant protection mechanism to counter the oxidative attack. But in the diseased state, ROS rises above the tolerance level and lung cells are not able to counter the ROS and thus succumb to irreversible lung cell damage. Antioxidant compounds were tested to protect the lung against those reactive oxygen intermediates. But, simple antioxidant therapy is not an effective approach to counter oxidative damage and combat lung cancer, as the concentrations of antioxidants to interact with lung cells become diluted. Hence, it is essential to develop a delivery system for vectoring antioxidants to lung cells. Liposome mediated drug delivery to lung cells is potentially significant among other delivery devices not only for its nontoxic nature, biodegradability, and non-immunogenetics but also for vectoring the encapsulated drug to a particular target organ. Furthermore, owing to the presence of mannosyl-fucosyl receptors on the surface of lung cells, mannose coated liposomes are effective in site-specific drug delivery to lung tissues.

Curcumin, a polyphenol compound, the principal curcuminoid of the Indian curry Spice turmeric, is known for its antitumor, antioxidant, anti-proliferative, anti-mutagenic, antiarthritic, anti-amyloid and anti-inflammatory properties (Mukherjee Nee Chakraborty et al., 2007). It is widely used as a dietary spice and coloring in cooking and as a herb in traditional Indian medicine.

The aim of this study is to optimize an antioxidant and anti-carcinogenic curcumin in mannosylated liposome formulation and to evaluate its mechanism of action in combating lung carcinogenesis by using an in vivo rat model of B(a)P-induced lung cell injury.

Methodology:

A. Animal experiment:

Adult male Swiss Albino Rats, each weighing approximately 100-120gm, were acclimatized to conditions in the laboratory (26-28˚C, 60-80% relative humidity, 12h light/dark cycle) for 7 days prior to the commencement of the treatment during which they were receiving food (purchased from Hindustan Lever Limited, Maharashtra, India) and drinking water. Sixty rats were divided into ten groups of six animals. For the 1st set of five groups, normal group was kept by injecting olive oil twice in a week for consecutive six weeks and normal food for 18 weeks. One experimental group was injected B(a)P (i.p. 50mg/kg b wt in 0.5ml olive oil) twice in a week for consecutive six weeks. Out of remaining three experimental groups, one group was injected (i.v.) with free Curcumin (0.5ml suspension of 0.2% tween 80 aqueous solution containing 0.33mg Curcumin) twice in a week for 16 weeks after four weeks of B(a)P treatment. Other two groups were provided (i.v.) liposomal and mannosylated liposomal Curcumin (each 0.5ml suspension containing 0.33mg liposomal and mannosylated liposomal

Curcumin respectively) twice in a week for 16 weeks after four weeks of B(a)P exposure. The 2nd set of five groups was repeated for another study. At the end of 18th week, rats in normal, P(a)P-control and other experimental groups were sacrificed and their lung tissues were removed and washed with cold physiological saline and either used for experiments or kept at -70˚C. The animal experiment has been approved by Institutional Animal Ethical committee.

B. Estimation of endogenous antioxidants level in normal, B(a)P and Curcumin treated rat lungs

For the determination of endogenous anti-oxidants defense such as GSH, SOD, GPx, GR, GST, catalase, lungs of normal and experimental animals were homogenized separately in 50mM chilled phosphate buffer pH 7.4 containing 1mM EDTA.

C. Estimation of GSH level

Glutathione level in tissue homogenate was determined by using tetrachloroacetic acid with EDTA as protein precipitating agent. The mixture was allowed to stand for 5 minutes prior to centrifugation for 10 minutes at 200g. The mixture was then transferred to a new set of test tubes and 0.3M phosphate buffer and Ellmen reagent (5, 5^1 dithiobis- 2 nitrobenzoic acid in 1% Na-citrate) were added. After completion of the total reaction, solutions were read at 412nm. Absorbance values were compared with a standard curve generated from known GSH concentration to evaluate liver homogenate GSH levels.

D. Estimation of SOD activity

The assay of superoxide dismutase for liver homogenate was performed with 10mM ferricytochrome c.

E. Estimation of GPx activity

To measure the GPx activity, homogenate containing the enzyme source was mixed with 0.25M potassium phosphate buffer, 25mM EDTA, glutathione reductase, 40mM glutathione(GSH), 20mM NADPH. The mixture was mixed and then incubated for 2 minutes at 37^0C. The reaction was initiated by adding t-butyl hydroperoxide at the final concentration of 0.3mM. The mixture was stirred and the absorbance was read immediately at 340nm at 1-minute intervals for 4 minutes. The absorbance change during the 2 to 4-minute interval was used to calculate enzyme activity. The activity was determined and expressed as µmol NADPH oxidized/min/mg protein.

F. Estimation of GR activity

GR was assayed. A 3ml reaction mixture contained 100mM phosphate buffer (pH 7.0), 1mM GSSG, 1mM EDTA, 0.1mM NADPH, and 25 to 50 µl enzyme extract. The reaction was started by adding the enzyme extract. The rate of NADPH oxidation was followed by monitoring the decrease in absorbance at 340nm with a recording spectrophotometer. The activity was expressed as µmol of NADPH oxidation/min/mg protein.

G. Estimation of GST activity

GST activity was determined in a total volume of 1.0ml, containing 100mM potassium phosphate buffer (pH 6.5) and 2mM each of GSH and 1-chloro-2-4-dinitrobenzene (final concentration). The rate of formation of S-2-4-dinitropgenylglutathione (a GSH-1-chloro-2,4-dinitrobenzene conjugate) by enzyme extract was quantified at 340nm using the extinction coefficient of 9.6L $mmol^{-1}$ cm^{-1} (Maiti and Chatterjee, 2000) and the activity was expressed as n mol/min/mg protein.

H. Estimation of catalase activity

The rat lung homogenate was used for catalase activities. The reaction mixture contained sodium phosphate buffer (0.05M, pH 7.0), 50mmol/L^{-1} H_2O_2 and 50µl of enzyme extract in a 3ml volume. The activity was assayed by monitoring the decrease in absorbance at 240nm as a consequence of H_2O_2 consumption and enzyme activity expressed as amount of H_2O_2 decomposed per minute per mg. of protein.

I. Lipid peroxidation assay

Lipid peroxidation in the lung homogenate was determined by measuring the amount of lipohydroperoxides. The lung cell membrane was extracted twice in a chloroform-methanol mixture (2:1, v/v). The pooled extract was evaporated to dryness under a nitrogen atmosphere at 25˚C and redissolved in cyclohexane. Lipids in cyclohexane solvent were assayed at 234nm and the results were expressed as µmol of lipohydroperoxide/mg protein by using an €m of 2.53 x10^4 L mol^{-1} cm^{-1}.

Results:

GSH level in the lungs decreased by the exposure of B(a)P, where that level increased by the treatment of curcumin (Table-1). SOD activity in the lungs reduced by the exposure of B(a)P, but this activity is found to increase by the treatment of curcumin (Table-1). GPx activity decreased by the exposure of B(a)P, but it increased by the treatment of curcumin (Table-1). GR activity of lung homogenate was reduced by the exposure of B(a)P, whereas this activity increased by the injection of curcumin to rats (Table-1). GST activity of rat lung homogenate decreased by the treatment of B(a)P but it increased by the treatment of curcumin (Table-1). Catalase activity of rat lung decreased with the treatment of B(a)P, whereas this activity increased with the treatment of curcumin (Table-1).

Table 1. Effect of curcumin on the changes in GSH, SOD, GPx, GR, GST and catalase activities in rat lung by the induction of B(a)P.

100xGSSG/GSH		SOD (Units/mg protein)	GPx µmole NADPH oxidation/min/ mg protein	GR µmole of NADPH oxidation/min/ mg protein	GST nmole produced/ mg protein	Catalase µmole H_2O_2 reduced/min/ mg protein
Normal	1.50±0.15	4.23±0.34	40.46±4.24	3.02±0.38	230±16.5	241±15.3
B(a)P treated	0.95±0.09*	2.52±0.19*	20.21±2.04*	1.51±0.13*	132±10.4*	111±9.2*
Curcumin treated	1.12±0.11 #	3.82±0.21 #	32.53±6.28 #	2.23±0.21 #	196±14.4 #	201±12.4 #

Each value was expressed as mean ± S.D. for 5 rats in each group. Statistical significance: *p<0.05, where B(a)P treated group compared with normal and #p<0.05, where curcumin-treated group compared with B(a)P treated group.

In my study, the lipohydroperoxides increased by the treatment of B(a)P where it decreased by the treatment of curcumin (Table-2).

Table 2. Effect of curcumin on lipid peroxidation in the lung of normal and experimental rats.

	Lipohydroperoxides (μmol/mg protein)
Normal	0.7±0.06
B(a)P treated (A)	1.3±0.11*
(A)+Curcumin treated	1.0±0.09#
Values are mean ± SD for 5 rats. *p<0.05 significantly different from normal. #p<0.05 significantly different from B(a)P treated.	

Discussion & Conclusion:

Lung cancer, the most common cause of cancer-related death in men and women, is responsible for 1.3 million deaths world-wide annually (WHO February 2006 Cancer), representing 18% of global cancer deaths (Field et al., 2006) where about 90% of lung cancer mortality is due to cigarette smoking (Chyou et al., 1992). There is a great variation in the prevalence of lung cancer in different geographical areas. Nearly 70% of all the new cases of lung cancer in the world occur in developed countries (Parkin et al., 1988). B(a)P is a significant pro-carcinogenic substance, which requires metabolic activation to electrophilic reactive metabolites for its carcinogenic activity (Gelboin, 1980). It is well established that B(a)P, after sequential metabolic activation principally by cytochrome P450, generates 7,8- diol – 9, 10- epoxide-benzo(a)pyrene, which is believed to be the ultimate carcinogenic metabolite of B(a)P (Su et al., 2006) that leads to the formation of DNA adducts and initiates mutations responsible for tumor development. The toxic manifestations of the carcinogenic intermediates of B(a)P are being considered caused primarily due to the imbalance between pro-oxidant and anti-oxidant homeostasis and also due to its ability to bind to sulphydryl groups of proteins and cellular non-protein thiols such as glutathione (GSH) and to inhibit energy production which may be exerted through excess production of ROS. This study will report on one of the mechanisms of lung carcinogenesis exposed by B(a)P in rat model. It will also focus on the mechanistic regulation of lung carcinogenesis by the exposure of curcumin. Mannosylated liposomal Curcumin may be a therapeutic tool because of its efficacy in combating lung carcinogenesis. Although progress has been made in reducing incidence and mortality rates and improving survival, lung cancer still accounts for more deaths. Moreover, progress can be accelerated by applying existing cancer control knowledge across all segments of the population and by applying new discoveries in cancer prevention, early detection and treatment (Ahmedin et al., 2009; Madhu et al., 2022; 2023).

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Chapter- 14

Exploration of The Therapeutic Effects of a Dietary Flavonoid Rutin

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Keywords: Rutin, Anti-inflammatory, Anti-carcinogen, Oxidative stress, neurodegenerative disorders, autoimmune disease

Abstract:

Phytochemicals, which are also known as phytonutrients, are secondary metabolites and natural bioactive compounds found in a wide variety of plants. They are abundantly present in foods like fruits, nuts, vegetables, whole grains and even in various parts of plants. There are different kinds of phytochemicals, namely, carotenoids, isoprenoids, polyphenols, phytosterols, saponins, dietary fibres, polysaccharides etc. Rutin is one of a such kinds of flavonoids that are widely found in asparagus, buckwheat, apples, figs, tea etc. Researchers report many therapeutic properties of rutin. Rutin has been reported to have a beneficial role in controlling various diseases such as cancer, hypertension, arteriosclerosis, diabetes, anti-inflammatory, cardiac diseases and obesity. In this chapter, we demonstrate a comprehensive study of various therapeutics activities of rutin.

Introduction:

India is cradle for a vast array of medicinal plants which are enriched with enormous phytochemicals. From ancient times, these medicinal plant-derived phytochemicals have served man and mankind to deal with different diseases and physiological challenges (Kar et al., 2022; Pawar et al., 2023; Thangavel et al., 2023). Flavonoids are a subset of the dietary phytochemicals present in fruits and vegetables of our daily consumption. Amongst various bioactive phytochemicals, Rutin is an important flavonol present in apples, citrus fruits, tea, grapes etc. (Figure 1). The main source of this polyphenolic flavonoid is buckwheat plant (Ganeshpurkar and Saluja, 2016). The name rutin comes from the plant *Ruta graveolens* L., which is a major source of rutin phytochemical. Another names of rutin are quercetin-3-O-rutinoside, rutoside, vitamin P and sophorin (Farha et al., 2020). The combination of flavonol

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quercetin and the disaccharide rutinose forms Rutin. It is mentioned that near about 130 therapeutic drugs existed in the market containing rutin in their composition (Satari et al., 2021). Rutin is well known with its various pharmacological attributes. It has antioxidant, anti-cancer, anti-inflammatory, anti-diabetic, anti-microbial, and anti-arthritic properties. The neuroprotective, cardioprotective, hepatoprotective characteristics of rutin are also well-known (Negahdari et al., 2020). Due to its pharmacological activity rutin is used in many therapeutic and medicinal preparations such as cardiovascular protective remedies, gastric lesion therapies, nephropathic treatments, as anti-inflammatories (Dong et al., 2020). The chemopreventive and chemotherapeutic effects of rutin make it a suitable anti-cancer agent to treat various kinds of carcinomas. Rutin exerts its anti-carcinogenic effects by suppressing cell proliferation, induction of autophagy and/or apoptosis and it also prevents metastasis and angiogenesis in a variety of cancers. (Farha et al., 2020). Rutin can also modify PI3K/Akt, Janus kinase/signal transducers and transcription-activators, NF-κB, mitogen-activated protein kinase (MAPK) and Wnt/β-catenin signalling in cancer (Imani et al., 2020). Reports also suggest that rutin can also be used in combination with conventional anticancer drugs for cancer treatment *in vitro* (Satari et al., 2021). In the following section, we have highlighted the chemical structure and multiple pharmacological features of dietary polyphenol rutin.

Chemical nature of rutin:

Rutin is non-toxic in nature and a glycosylated version of rhamnose-glucose disaccharide and quercetin. The molecular weight of rutin is 610.53 Dalton (Farha et al., 2020). Its chemical name is (2-(3,4-dihydroxyphenyl)-4,5-dihydroxy-3-[3,4,5trihydroxy-6-[(3,4,5-trihydroxy-6 methyl-oxan-2-yl)oxymethyl]oxan-2-yl] oxy-chromen-7-one (Figure 1). This lipophilic phytochemical is poorly water soluble but highly soluble in organic solvents such as methanol, ethanol, pyridine etc. Rutin has low stability and low bioavailability due to its low solubility in water (Negahdari et al., 2020).

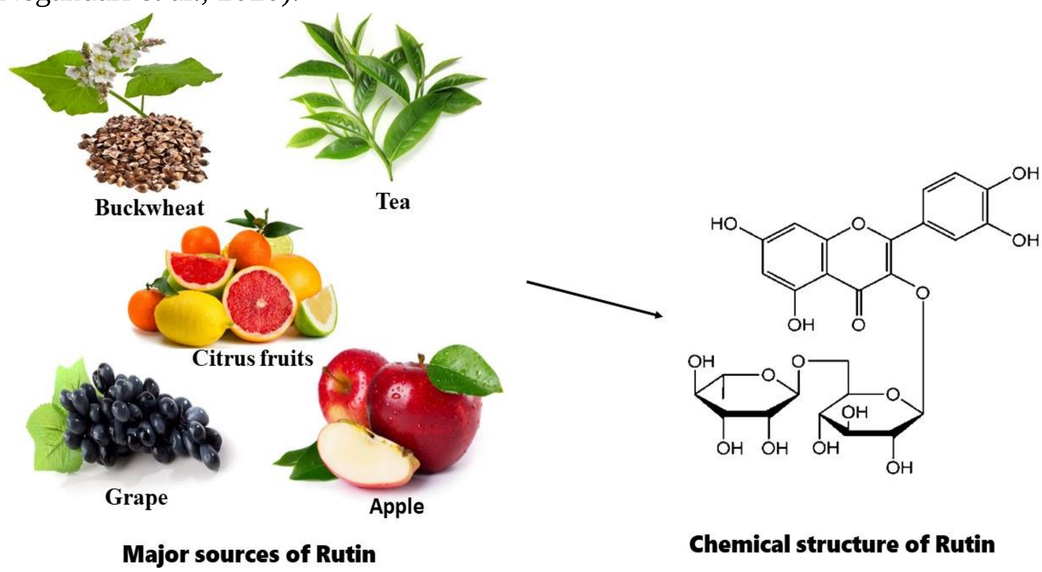

Figure 1. Major sources and chemical structure of Rutin

Anti-carcinogenic effect of rutin:

Rutin can detoxify different carcinogenic agents. It is a potent chemopreventive and radio protective agent. As per reports, rutin can act against Benzo (α) pyrene-7, 8-diol-9, 10-epoxide, which is a potent carcinogen. It can prevent oxidative DNA damage by different mutagens like, mitomycin C, benzo (α) pyrene, methyl-methanesulfonate, hydrogen peroxide, 4-(methylnitrosamino)-1-(3-pyridyl)-1- butanone (NNK) and 13-hydroperoxyoctadecadienoic acid. Owing to its radio protective effect, rutin can reduce UV irradiation induced inflammation. The solution of rutin and DMSO can protect UV-B irradiated cells from being degradation (Farha et al., 2020).

Therapeutic efficacies of Rutin in the treatment of cancer and other diseases:

Anti-cancer properties of rutin:

Evidences from different studies indicate that rutin has the capability to inhibit different types of cancer cell proliferation. According to various study reports, rutin can be used to treat breast, pancreas, glioma, colon, skin, lung, ovarian, cervical, prostate, liver cancer and as well as neuroblastoma (Imani et al., 2020; Mehta et al., 2023). The effectiveness of rutin is extended from different types of cancers to carcinogenic agents. Various anti-cancer properties and associated signalling pathways of rutin have been summarized in Figure 2.

Inhibition of cell cycle progression:

Rutin can target cell cycle pathways during cancer treatment. It promotes cell cycle arrest at different cell cycle check points like, G1, S, G2/M. It can successfully alter the cell cycle regulatory proteins i.e., cyclins, cyclin-dependant kinases (CDKs) and also the CDK inhibitors (CKIs). According to recent researchers, it can also increase the expression of cell cycle-related genes, CDK1 and p21 and reduce Cyclin B expression during G2/M phase arrest. It can inhibit the phosphorylation of GSK-3b and promote apoptosis in cancer cells. In Glioma GL-15 cells rutin promote G2 phase cell cycle arrest and apoptosis (Farha et al., 2020).

Induction of apoptosis and autophagy in cancer cells:

Rutin can modulate both the intrinsic or mitochondria-mediated pathways and extrinsic or death receptor-mediated pathways of apoptosis in cancer cells. In the case of neuroblastoma (LAN-5), rutin targets intrinsic apoptotic pathway by reducing the ratio of B-cell lymphoma 2 (Bcl2) protein and Bcl-2-associated X protein (Bax) in cellular level. In colon cancer cells (HT-29) rutin can trigger both the apoptotic pathway by increasing Bax, caspase-3, 8 and 9 expression and decreasing Bcl-2 expression. In another colon cancer cell line HCT 116, rutin activate caspase-3 expression (Farha et al., 2020). TNF-α accompanied by rutin can trigger the apoptosis of (A549) human lung cancer cells by GSK-3β modulation. In leukaemia (K562 cell line) rutin can promote intrinsic apoptotic pathways for cancer prevention (Imani et al., 2020). In human breast cancer cells (MCF-7), rutin can induce the expression of tumour suppressor gene p53, phosphatase and tensin homologue (PTEN) and promote cancer cell apoptosis. In pancreatic cancer cells (PANC-1), prostate cancer cells (LNCaP) and ovarian cancer cell (OVCAR-3), rutin downregulates cancer cell proliferation and upregulates cellular apoptosis (Farha et al., 2020).

Rutin can also mediate autophagy in CA9-22 (oral cancer cell line), A549 and THP-1 (human leukemia) cell lines by reducing TNF-α production, Beclin-1 upregulation and NF-κβ suppression respectively. It can also target LC3-II activation and ATG5/12 upregulation (Park et al., 2016).

Inhibition of angiogenesis:

Angiogenesis is an important phenomenon in tumour development and progression. Rutin bears anti-angiogenic property. It can significantly decrease the development and tube formation of endothelial cells by lowering the generation of angiogenesis inducers like TNF- α, IL-1β and VEGF. *In vivo* experiments have indicated that rutin obstructs the angiogenesis process. Rutin can also reduce VEGF expression, which implies to its anti-angiogenic characteristics (Farha et al., 2020).

Increase of Reactive Oxygen Species (ROS):

ROS sustains an equilibrium in the aggregation and degradation of normal cells. In cancer cells the balance is disrupted, which in turn increases ROS accumulation and enhances the oxidative stress. At a certain level, oxidative stress can initiate cellular apoptosis and check cancer development. As per research studies, C33A (cervical cancer cell), HepG2, MCF-7 cell lines have shown ROS-mediated apoptosis after rutin treatment. It can also increase ROS production in melanocyte cells to destroy those cells (Farha et al., 2020; Dey & Guha, 2020). In fibroblast cells, rutin exerts cytoprotective effect and also inhibits the ROS accumulation triggered by UV irradiation (Gegotek et al., 2017).

DNA damage regulation:

Rutin is a potent DNA damage inducing agent in cancer (Thangavel et al., 2023). Doxorubicin mediated DNA damage is managed by rutin treatment in hepatocellular carcinoma cell line (HepG2) (Imani et al., 2020). In BRCA mutant cells, this polyphenol can initiate DNA abrasion (Maeda et al., 2014). But there is a lack of information about rutin mediated DNA damage related signalling pathways. Therefore, we can focus on that particular site of research in the near future.

Inhibition of metastasis:

Metastasis is a crucial process for tumour progression in different parts of the body. Rutin plays a vital role in inhibition of tumour metastasis. It can obstruct the formation of lung tumour nodule and its metastasis in B16-Fl0 melanoma bearing mice model (Swiss mice and C57BL/6 mice). Rutin is also a potent matrix metalloproteinase inhibitor. Metastatic cell invasion and migration is also modulated by rutin treatment in HT-29 and A549 cancer cells (Imani et al., 2020; Selvaraj et al., 2016).

Anti-inflammatory activity:

Enzymes associated with inflammation and inflammatory responses are protein kinase C, cyclooxygenase, phosphoinositide 3-kinase (PI 3-kinase) and lipoxygenase. Prostaglandins and leukotrienes are important inflammatory mediators. Rutin can modulate these agents negatively by exerting an anti-inflammatory activity upon cells. It can downregulate the pro-inflammatory cytokines like, IL-1β, TNF-α, and IL-6 and also the NF-κB to reduce inflammation (Negahdari et al., 2020; Pandey et al., 2020; Bee et al., 2023).

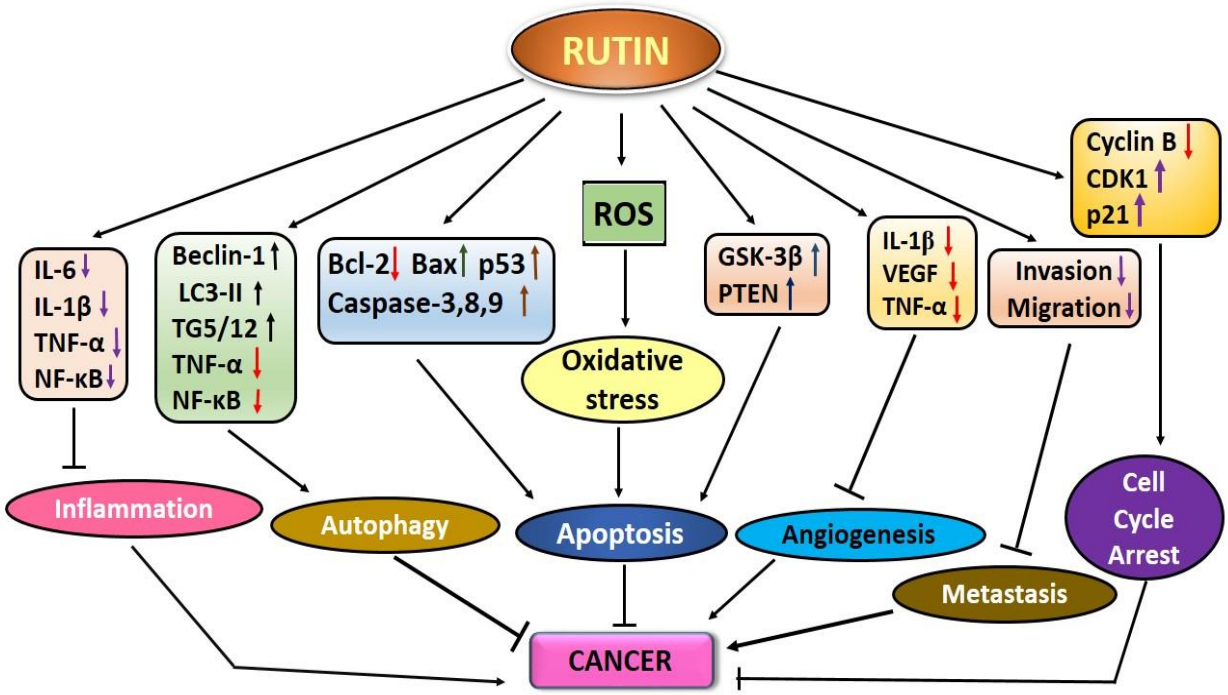

Figure 2. A schematic representation of different signalling pathways and signalling molecules involved with the anti-cancer properties of rutin

Neuroprotective properties of rutin in treating central nervous system disorders:

Rutin has strong neuroprotective activity against ischemia induced neural apoptosis. It can significantly decrease lipid peroxidation by enhancing the level of different endogenous antioxidant enzymes. Study reported that administration of rutin at 10mg/kg can improve memory retrieval in rat model. Daily administration of rutin also reverses the trimethyltin associated hippocampal -pyramidal neuron damage and spatial memory loss (Patel and patel, 2019). Rutin acts as anti-convulsant flavonol and positively regulate the action of GABA (Gamma-aminobutyric acid) receptor complex, so, it is useful in epileptic convulsions. Neural crest, an important progenitor cells could become neurons and other mesenchymal cells. Research demonstrated that treatment with rutin can protect trunk neural crest cells viability via modulating the PI3K/ERK2 axis, but it doesn't alter or block cell proliferation and differentiation activity (Ganeshpurkar and Saluja, 2016).

Alzheimer’s disease:

Alzheimer’s disease (AD) is the most frequent progressive neurological disorder that causes progressive neuronal loss due to accumulation of amyloid plaques and neurofibrillary tangles (Dumon et al., 2011). In human AD model, oxidative stress occurs before the formation of amyloid plaques in the brain (Cheignon et al., 2018). Rutin has free radical scavenging property and it can highly reduce Aβ25–35 fibril formation related neurotoxicity. Multifunctional rutin can decrease the Aβ aggregation by enhancing the level of several antioxidant enzymes such as superoxide dismutase, catalase, glutathione, glutathione peroxidase etc. along with significantly decrease in production of ROS, nitric oxide, nitric oxide synthase (Enogieru et al., 2018). Xu et al. reported that when rutin is orally administrated (100mg/kg) for 6 weeks, it can effectively decrease the oligomeric form of Aβ, IL-1 and IL-6 level. By this way, it can supress astrocytosis and microgliosis in transgenic mice brain. Another study shows that rutin can improve both memory and cognition deficits in Aβ25–35 treated mice (Enogieru et al., 2018).

Parkinson’s disease:

Parkinson’s disease (PD) is the second most frequent progressive neurodegenerative disorder and is characterized by loss of dopaminergic (DA) neurons (Weng et al., 2018; Haloi et al., 2023). 6-hydroxydopamine (6-OHDA) has been used as an *in vitro* model of PD. In this study, pretreated rutin can reduce the toxicity of 6-OHDA in dose-dependent manner and also exhibit the cytoprotective activity in 6-OHDA treated PC12 cell line (Enogieru et al., 2018). In addition, pretreated rutin can decline the PD related genes expression including ubiquitin carboxyl-terminal esterase L1(UCHL1), PARK2 (Parkin gene), DJ-1 (deglycase-1) and proapoptotic genes like Caspase3, Caspase7 etc. in conjugation with a significantly enhanced expression of antiapoptotic genes like optic atrophy type1 (Opa1) and N-ethylmaleimide sensitive fusion protein (NSF). It also increased the tyrosine hydroxylase mediated dopamine production (Enogieru et al., 2018). In 6-OHDA administrated Wistar rat model, the application of rutin can improve impaired motor coordination and locomotion activity (Enogieru et al., 2018). In another study rotenone treated SH-SY5Y cells were used as a PD *in vitro* model to investigate the effect of rutin on PD. Here, rutin inhibits the rotenone mediated cell cytotoxicity by inhibition of ROS production and or downregulation of JNK/p38 MAPK cascade. It also regulated the mitochondrial membrane potential and supress the apoptosis pathway related different gene (Bax, Bcl-2, caspase-9 and caspase-3) expression (Enogieru et al., 2018).

Huntington’s disease:

Huntington’s disease (HD) is an inherited (autosomal dominant) neurodegenerative disorder which is characterized by dysregulation of cognitive, motor and behavioural abnormality. In case of HD destruction of neurons mainly located in striatum. In 3-Nitropropionic administrated Huntington’s disease rat model rutin at the dose of 25-50mg/kg can prevent neural degeneration by upregulating antioxidant enzymes defence system, reduce protein peroxidation and recover behavioural alterations (Enogieru et al., 2018).

Stroke:

Stroke is known as death of brain tissue, which is characterized by inadequate flow of blood or oxygen to the brain due to presence of artery blockage (Crack and Taylo, 2005). According to the World Health Organisation reports, large number of world population are suffering from stroke. According to research reports, it is considered that high level of ROS production is associated with stroke-induced brain injury (Allen and Bayraktutan, 2009). Rutin can considerably protect brain from focal cortical ischemia which is caused by thermocoagulation of motor and somatosensory blood vessels, as well as restoring the normal function of sensorimotor (Ganeshpurkar and Saluja, 2016).

Cardiovascular disease:

Ischemia-reperfusion **(**I/R**)** injury is a well-known deleterious effect commonly seen after myocardial infarction when the blood flow resumes in previously ischaemic or O_2 deprived tissue. In ischemia-reperfusion injury, oxidative stress is mainly responsible for cell death by increasing the lipids and protein oxidization (Briegera et al., 2012; Madhual et al., 2023). *In vivo* experimental study shows that rutin (5, 10mg/kg doses) has a strong cardioprotective effect against ischemia–reperfusion induced myocardial infarction. Application of rutin can significantly decrease the oxidative stress-mediated lipid peroxidation due its antioxidative properties (Patel and Patel, 2019). The higher expression of TGβ1 is responsible for dilated cardiomyopathy, hypertrophic cardiomyopathy and interstitial fibrosis. In coronary heart disease *in-vivo* model application of rutin can decrease the TGβ1 expression along with increased expression of p-ERK1/2 and p-Akt. The expression of ERK/ Akt is very important for normal cardiac function. This report also demonstrates that the administration of rutin (45mg/kg) in CHD (congenital heart defects) pig model has an ability to reduce the systolic internal diameter or infract size of the myocardium (Lv et al., 2018). Application of rutin restores the production of different cardiac marker enzymes such as aspartate transaminase, alanine transaminase, creatine kinase, acetate dehydrogenase etc. (Ganeshpurkar and Saluja, 2016). Rutin also exhibits its cardioprotective effect by reducing heart homogenate protein nitration (Patel and Patel, 2019).

Hepatoprotective activity:

Cirrhosis is known as liver tissue scar or damage of hepatocytes which ultimately result in death of hepatocytes or impaired liver function. Several research shows that application of antioxidant agents may reduce oxidative stress induced liver cirrhosis. Recently, several research investigates the hepatoprotective activity of rutin in hepatic injury. Among these experiments one of them experiment demonstrates that treatment with rutin can effectively reduce carbon tetrachloride induced hepatic injury in *in vivo* system; in serum, it can decline the production of aspartate aminotransferase, alkaline phosphatase and alanine aminotransferase which is induced by carbon tetrachloride (Ganeshpurkar and Saluja, 2016).

Anti-diabetic property:

Diabetes, a lifelong metabolic illness which is associated with hyperglycaemia (Sur et al., 2023; Biswas et al., 2023; Biswas et al., 2023). Insulin resistance or low production of insulin from pancreatic islets is main cause of hyperglycaemia (Ganeshpurkar and Saluja, 2016; Sarkar et al., 2023). Research have shown that long-term administration of streptozotocin in rats results in excessive superoxide production in pancreatic beta cells, increased plasma glucose level and reduced insulin production. In this study, the administration of rutin can restore normal insulin level and it also helps in refunctioning of the glycolytic enzymes in streptozotocin-treated diabetic rat. In addition, regeneration of pancreatic islets and reduction of fatty acid infiltration in diabetic rats were found after rutin treatment. According to another study report, rutin also elevates the activity of insulin receptor kinase and by this way it can stimulates insulin signaling pathway. Upregulation of insulin signaling pathway can enhance GLUT4 mediated glucose uptake (Ganeshpurkar and Saluja, 2016).

Rheumatoid arthritis:

Rheumatoid arthritis (RA) is an autoimmune disease. Due to this, joints are affected where synovial inflammation causes cartilage and bone damage. In collagen-induced (CIA) *in vivo* model, administration of gold nanoparticles (NPs) loaded rutin (R-AuNPs) and without NPs conjugated rutin exhibits strong anti- rheumatic arthritis property by reducing the level of different oxidative stress markers/mediators including iNOS, NF-κB etc. (Gul et al., 2018; Singh & Sharma, 2023). Sun et al. reported that rutin at 15 mg/kg dose can significantly decline the proinflammatory cytokines (TNF- α, IL-1 β) production and NF-κB p65 expression in arthritis rat model. Histopathological experiment of above study demonstrated that the synovial hyperplasia, infiltration of inflammatory cells and erosion of bone/cartilage was reduced after rutin administration (Sun et al., 2017).

Nephropathy:

Nephropathy is one of the lethal disease responsible for high death rate throughout the world. Research investigation suggested that rutin intake may lead the way-out of oxonate-stimulated renal dysregulation and hyperuricemia. Administration of rutin can significantly reduce the level of blood urea nitrogen, serum urate and kidney uromodulin (Ganeshpurkar and Saluja, 2016).

Anti-microbial activity:

Rutin has shown antibacterial, antiviral, antifungal activity against different pathogens or microorganisms. Rutin exhibits antibacterial effects on *Klebsiella sp.*, *Shigella sp.*, and *Proteus vulgaris* (Ganeshpurkar and Saluja, 2016). Rutin is an effective antiviral phytochemical compound that significantly kill avian influenza strain H5N1, in this experiment antiviral property of rutin is determined in the 'Madin-Darby canine kidney' by plaque inhibition assay (Ibrahim et al., 2013). Another study demonstrated that only 60 µg/ml of concentrated rutin can exhibit strong antifungal activity against *Candida gattii* (fungus). Application of rutin can successfully reduce the *C. albicans* induced septic arthritis (Ganeshpurkar and Saluja, 2016).

Reproductive disease:

It has been reported that rutin can reduce lipid peroxidation in sperm. In type1 diabetes mellitus patients, administration of rutin can reduce oxidative stress mediated testicular tissue damage and improve reproductive health (Moretti et al., 2012; Ganeshpurkar and Saluja, 2016).

Discussion & Conclusion:

Rutin is a natural bioactive compound with multiple pharmacological attributes. A plant derived dietary polyphenol rutin has significant metabolic effects (Farha et al., 2020; Sarkar et al., 2021; Satari et al., 2021; Ghosh et al., 2022). It is a potent phytomedicine that can be used to treat multiple health issues like neuronal disorder, cardiac diseases, arthritis, cancer, diabetes, liver disease and reproductive problems. Being a potent free radicle scavenger, it can act against body's oxidative stress and can detoxify carcinogens. We have focused more on the anti-cancer properties exerted by rutin. Different signalling pathways and different signalling molecules are employed in the treatment of breast, brain, ovarian, cervical, oral, liver, lung and other cancers. Apart from that other therapeutics aspects of rutin have been described in this chapter. Both the *in vivo* and *in vitro* trials with different modifications of rutin are ongoing to find its maximum potencies. *In vivo* information are lacking in this regard, therefore further investigations are needed to prepare a human safety profile with different therapeutic benefits of rutin.

Conflict of Interest:

The authors declare no conflict of interest.

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Chapter- 15

Revolutionizing Life Science Research: Field Emission Scanning Electron Microscope as an Invaluable tool for Microscale Exploration

Priyajit Chatterjee

Keywords: Field Emission Scanning Electron Microscope (FE-SEM), Life-Science Research, Microscale Exploration, Nanotechnology, High-resolution Imaging, Analytical Techniques

Abstract:

Field Emission Scanning Electron Microscopy (FE-SEM) represents the advanced and sophisticated evolution of traditional Scanning Electron Microscopy (SEM). Cutting-edge technologies, particularly the Field Emission Scanning Electron Microscope (FE-SEM), are propelling rapid advancements in life science research at the microscale. This abstract explores the contribution of FE-SEM in life science research, revealing its crucial role in advancing our comprehension of biological structures at unprecedented resolutions. FE-SEM's significance lies in its ability to provide high-resolution imaging of biological specimens, enabling scientists to investigate into intricate details at the microscale level. The instrument's field emission electron source enhances imaging capabilities, delivering exceptional spatial resolution and depth of field. This allows for the visualization of subcellular structures, cellular organelles, and nanoscale features crucial for unravelling the complexities of biological systems. Moreover, FE-SEM facilitates the study of dynamic biological processes through in-situ imaging, offering insights into cellular interactions and morphological changes over time. Its versatility extends to three-dimensional imaging, opening new avenues for comprehensive analyses of complex biological structures. The integration of advanced analytical techniques, such as energy-dispersive X-ray spectroscopy and electron backscatter diffraction, further enhances the capabilities of FE-SEM, enabling researchers to investigate elemental compositions and crystallographic information at the microscale. In conclusion, the Field Emission Scanning Electron Microscope emerges as an instrument, reshaping life science research by offering unparalleled insights into the intricate realm of microscale biology. The Field Emission Scanning Electron Microscope (FE-SEM) captures high-resolution images, observes how things change over time, and studies tiny details of structures. This makes FE-SEM an important instrument in modern microscopy, helping academicians to explore and discover more about the mysteries of life.

Introduction:

In the dynamic landscape of life science research, technological advancements continue to drive unprecedented progress, enabling academicians to explore the intricate realms of biological structures with unique precision. One such revolutionary tool at the forefront of microscale exploration is the Field Emission Scanning Electron Microscope (FE-SEM). This leading-edge instrument has emerged as an invaluable asset, propelling the boundaries of understanding in life sciences to new frontiers (Gnauck et al., 2001). The conventional scanning

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electron microscope (SEM) has long been an indispensable tool in life science research, offering high-resolution imaging of surfaces at the nanoscale. However, the limitations of traditional SEMs, particularly in terms of spatial resolution and signal-to-noise ratio, have spurred the development of the Field Emission Scanning Electron Microscope. The FE-SEM overcomes these limitations through the implementation of field emission sources, facilitating enhanced electron beam brightness and a finer probe size, thereby achieving unparalleled imaging capabilities (Lippens et al., 2019 and Lane et al., 2018). The fundamental principle underlying FE-SEM lies in its utilization of field emission cathodes, typically composed of tungsten or other refractory materials, which emit electrons when subjected to a strong electric field.

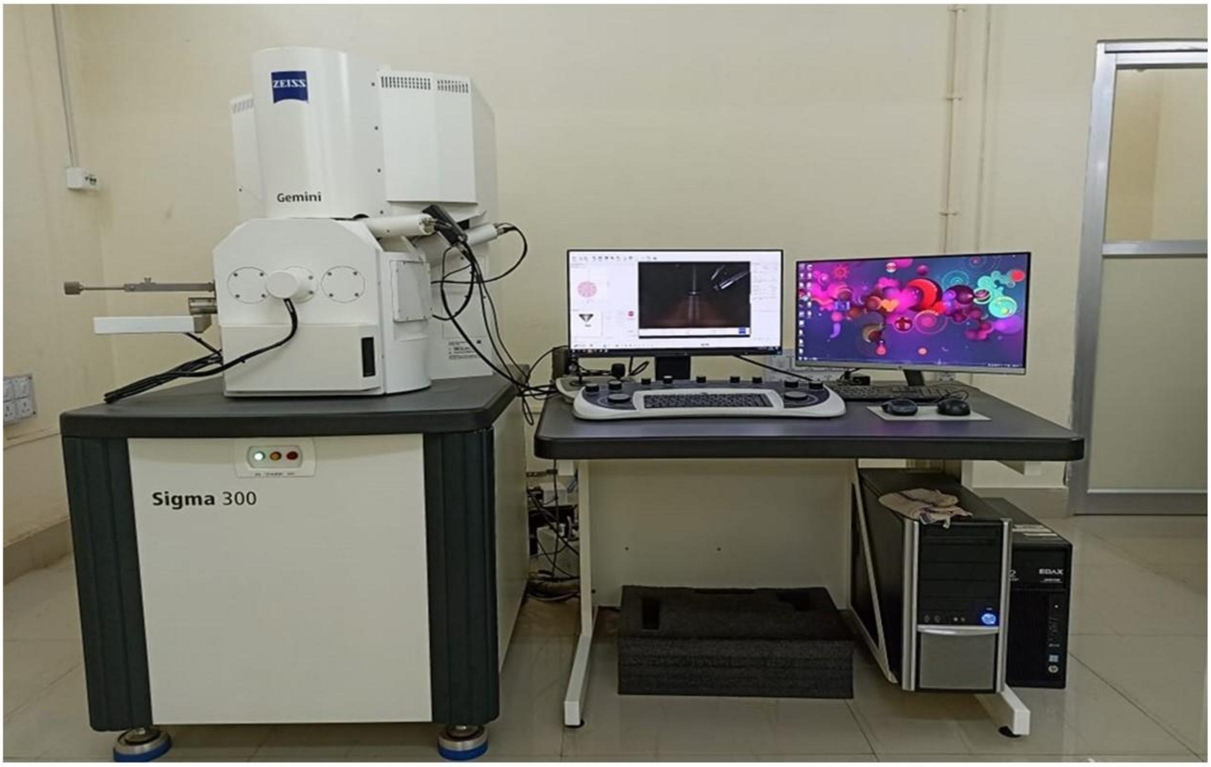

Figure 1. Field Emission Scanning Electron Microscope (installed at FE-SEM Laboratory, University Science Instrumentation Centre, The University of Burdwan, Make: Carl Zeiss, Model: Gemini 300)

This results in a highly focused and intense electron beam, capable of illuminating minute details of biological specimens with remarkable clarity. The FE-SEM's superior imaging capabilities have propelled it into the forefront of life science research, enabling scientists to unravel the intricacies of cellular and subcellular structures with unprecedented detail. This chapter objects to explore the transformative impact of the Field Emission Scanning Electron Microscope on life science research, shedding light on its technological foundations, key features, and the myriad of applications that have revolutionized our understanding of biological systems (Breton et al., 1999). By exploring into recent research, studies and advancements, we aim to highlight how the FE-SEM has become an indispensable instrument in unravelling the intricacies of life at the microscale.

Field-Emission Scanning Electron Microscope is more sophisticated instrument:

Field-Emission Scanning Electron Microscopy is more sophisticated than Scanning Electron Microscopy. Distinctions between a conventional Scanning Electron Microscope (SEM) and a Field-Emission Scanning Electron Microscope (FE-SEM) can be outlined (Bogner et al., 2007 and Kubota et al., 2018) in various following aspects:

Enhanced Electron Source:

- **SEM:** Typically uses a thermionic electron gun where electrons are emitted from a heated tungsten filament.
- **FE-SEM:** Utilizes a field emission electron gun, where electrons are emitted from a sharp metal tip or small area on the sample surface through the quantum mechanical tunnelling effect.

Better Electron Emission Mechanism:

- **SEM:** Employs thermionic emission, where electrons are emitted due to the high temperature of the tungsten filament. Typically has a lower brightness due to the nature of the thermionic emission process.
- **FE-SEM:** Relies on field emission, where electrons overcome a potential barrier at the sample surface, resulting in sharper and more focused beams. Exhibits higher brightness, contributing to improved imaging capabilities and increased signal-to-noise ratios (Pawley et al., 1997 and de Boer et al., 2016).

Improved Brightness and Beam Coherence:

- **SEM:** Generally, has lower brightness and beam coherence compared to FE-SEM.
- **FE-SEM:** Offers higher brightness and coherence, contributing to improved resolution and imaging capabilities.

Higher Resolution:

- **SEM:** Provides lower resolution, typically in the range of several nanometres.
- **FE-SEM:** Offers higher resolution, often achieving sub-nanometre levels, making it superior for detailed imaging of fine structures (Joy et al., 1993).

Increased Magnification Capabilities:

- **SEM:** Provides high magnification but may be limited in achieving extremely high magnifications.
- **FE-SEM:** Capable of achieving extremely high magnifications, making it suitable for imaging at the atomic and molecular scales.

High-Vacuum Environment:

- **SEM:** Operates under a moderate vacuum environment.
- **FE-SEM:** Requires a high-vacuum environment to minimize electron scattering and absorption by air molecules, ensuring efficient imaging.

Charging Effects Mitigation:

- **SEM:** Suitable for both conductive and non-conductive samples without the need for conductive coatings.
- **FE-SEM:** Generally, requires conductive coatings on insulating samples to prevent charging effects.

FE-SEM may require conductive coatings on insulating samples to prevent charging effects (Lippens et al., 2019), but the sophisticated electron optics and sample handling mechanisms help mitigate these challenges more effectively than in traditional SEM.

Specialized Applications:

FE-SEM is often preferred for advanced scientific and industrial applications, such as biological research, nanotechnology and materials science where the need for detailed imaging at the atomic scale is critical (Mohammadi-Gheidari et al., 2011). Its sophistication makes it suitable for studying a wide range of materials with exceptional precision.

Complex Instrumentation:

The design and construction of FE-SEM instruments involve more intricate and sophisticated components, leading to a higher level of complexity compared to SEM instruments. This complexity allows for greater control and precision in imaging.

In summary, FE-SEM offers superior resolution and imaging capabilities compared to conventional SEM (Bogner et al., 2007), making it the preferred choice for applications requiring extremely detailed and high-magnification imaging of surfaces.

Basic Principles of Image Formation:

Field-Emission Scanning Electron Microscopy (FESEM) is a powerful technique used for imaging the surface of materials at high magnifications (De Goede et al., 2017). The basic principles of image formation in SEM involve electron beam interaction with the specimen, detection of signals, and their conversion into images. Here are the key principles:

- **Electron Beam Generation:** A beam of electrons is generated by an electron gun within the FESEM. This typically involves a field emission gun (FEG) as the electron source, where as in normal scanning electron microscopy.
- **Electron Beam Focus:** Magnetic lenses are used to focus the electron beam onto the specimen. This allows for high spatial resolution imaging.

- **Specimen Interaction:** When the focused electron beam interacts with the specimen, several processes occur, including elastic and inelastic scattering. The majority of the signals used for imaging come from these interactions.
- **Elastic Scattering (Backscattered Electrons, BSE):** High-energy electrons can undergo elastic scattering with the atomic nuclei of the specimen. Backscattered electrons (BSE) are those that are scattered back towards the detector. The intensity of BSE is related to the atomic number of the elements in the specimen (Crewe et al., 1973).
- **Inelastic Scattering (Secondary Electrons, SE):** Low-energy electrons, resulting from inelastic scattering, can be emitted from the specimen surface. These secondary electrons (SE) carry information about the surface topography. SE imaging provides detailed surface information (De Goede et al., 2017).
- **Detectors:** Different detectors are used to collect various signals. BSE detectors capture signals related to compositional variations, while SE detectors are used for topographical information. Other detectors may be employed for specific applications, such as energy-dispersive X-ray spectroscopy (EDS) or Energy-dispersive X-ray analysis (EDAX) for elemental analysis. The SE detector captures electrons that are ejected from the sample surface due to the incident electron beam. The resulting images provide detailed topographical information about the sample. In-lens detectors are a type of secondary electron detector where the detector is located inside the electron optical column, close to the final lens. This design allows for efficient collection of secondary electrons and improved signal-to-noise ratio. In-lens detectors can provide enhanced imaging capabilities and are often used for high-resolution imaging.
- **Signal Processing and Image Formation:** The signals collected by detectors are processed and converted into images. Contrast in the images is often related to variations in the composition, density, or topography of the specimen

Biological sample Preparation for Field-Emission Scanning Electron Microscopy:

Preparing biological samples for Field-Emission Scanning Electron Microscopy involves several specialized steps to maintain the structural integrity of the samples and achieve high-resolution imaging. Here's a detailed guide for biological sample preparation:

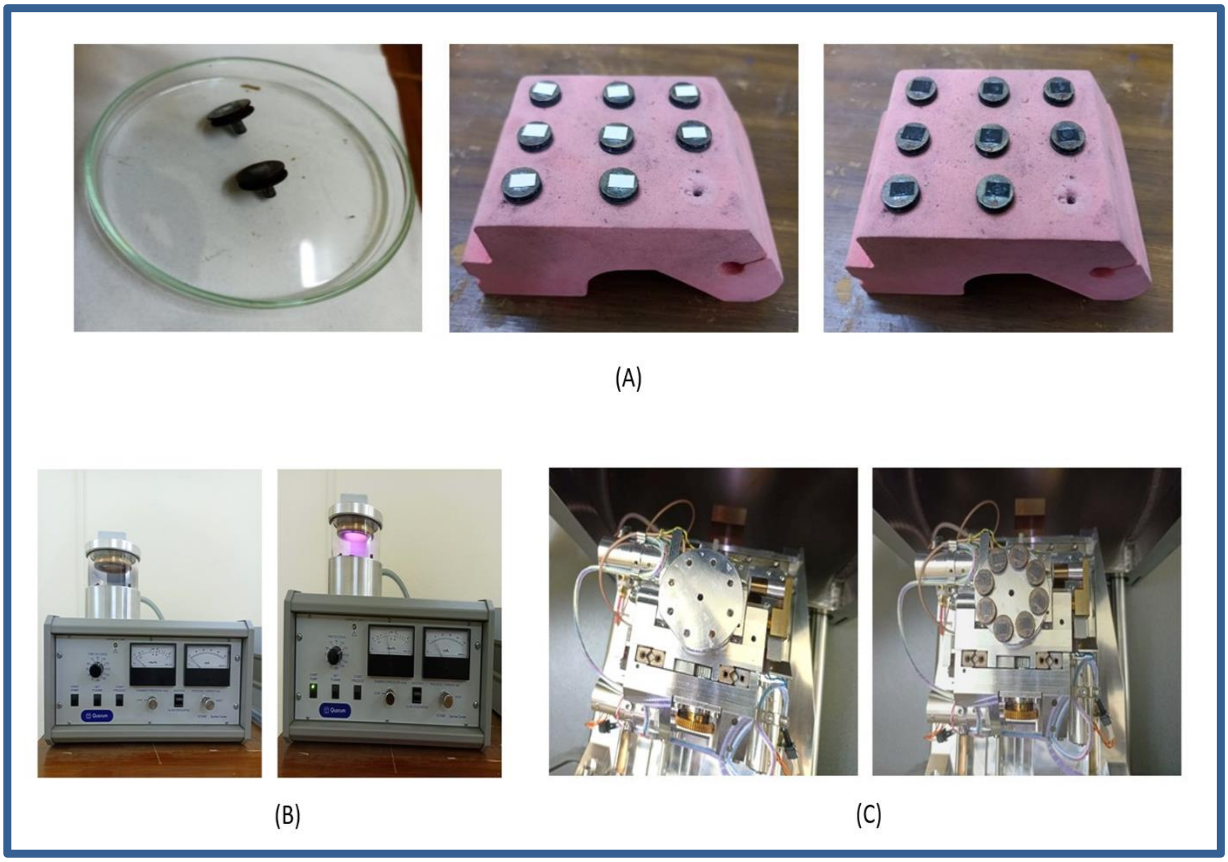

Figure 2. Prior Processing of Samples before FE-SEM study (A) metallic stubs, adherence of carbon tape on the stub and mounting the samples on the FESEM stub, (B) before and during the process of sputter coating, (C) before and after the loading of the stubs on the sample holder within FE-SEM apparatus

A. Fixation: Select a fixative that preserves cellular structures. Common fixatives include glutaraldehyde and formaldehyde. Glutaraldehyde is a strong cross-linking fixative, meaning it forms covalent bonds between proteins and other biomolecules. This property helps to stabilize the cellular structures and provides good preservation of ultrastructural details (Palay et al., 1962 and Sabatini et al., 1963). It is particularly useful when preservation of cellular ultrastructure is critical, making it a common choice for electron microscopy. Formaldehyde is a milder cross-linking fixative compared to glutaraldehyde. It primarily reacts with amino groups, forming methylene bridges. Formaldehyde is often chosen when preserving antigenicity for immunolabeling studies is crucial. It is suitable for samples intended for both immunofluorescence and subsequent SEM studies. Glutaraldehyde enhances electron density, leading to better contrast in electron micrographs. Glutaraldehyde penetrates tissues relatively slowly, so it may not be suitable for larger or thicker samples. Formaldehyde penetrates tissues more rapidly than glutaraldehyde, making it suitable for larger or thicker samples. For complex structures or delicate samples, a mixture of both fixatives can be used. Ensure that the fixative penetrates the sample thoroughly. The choice of fixative and duration of fixation depend on the specific biological material. Smaller samples or those requiring high-resolution ultrastructural details may benefit more from glutaraldehyde, while larger samples or those requiring antigen preservation might be better suited to formaldehyde.

B. Post-Fixation Processing: Secondary fixation using osmium tetroxide (OsO_4), which is a heavy metal stain that enhances the contrast of biological specimens, particularly cell membranes and lipid-rich structures. This metal stain binds to lipids and proteins, increasing the electron density of these regions and enhances visibility. Post-fixation is performed if additional contrast is needed, but be cautious as it can lead to sample shrinkage. Osmium tetroxide is highly toxic and should be handled with extreme care. It is usually used in a well-ventilated fume hood. The duration of osmium tetroxide post-fixation should be optimized based on the specific requirements of the sample and the desired contrast enhancement.

C. Dehydration: Gradually dehydrate the sample using a series of increasing ethanol concentrations or other dehydration agents. This process replaces water with a substance compatible with the vacuum environment of the SEM.

D. Critical Point Drying: Critical point drying (CPD) is often employed to remove the remaining liquid from the sample without causing collapse or distortion during the drying process. This method uses liquid carbon dioxide, preventing surface tension-related artifacts. This step is crucial for maintaining the sample's structural integrity during FE-SEM imaging.

Figure 3. Critical Point Dryer

The critical point is the temperature and pressure at which the liquid and gas phases coexist. Replace the dehydrating agent with a non-polar solvent like liquid CO_2 and slowly increase the pressure and temperature until the critical point is reached. Biological samples, especially those with intricate structures such as cells and tissues, contain water within their structures. As the sample is dehydrated, the water is gradually replaced with a less dense medium (e.g., ethanol) (Nguyen et al., 2016).

As the sample continues to dehydrate, there is a point where the liquid-to-gas phase transition occurs. If the dehydration process is abrupt, the surface tension of the liquid can cause collapse or distortion of delicate structures. Critical point drying avoids this issue. This is particularly important for preserving the fine details of biological specimens, including cell membranes, organelles, and other intricate features. The avoidance of collapse during critical point drying results in a more open and porous structure in the sample, which allows for better penetration of electrons during SEM imaging. This, in turn, leads to improved contrast and resolution in the resulting images. FE-SEM operates in a vacuum environment. Critical point drying removes the remaining liquid from the sample, making it compatible with the vacuum conditions inside the SEM chamber. Critical point drying is particularly beneficial for fragile or soft samples, such as biological tissues, which can be easily deformed or damaged during the drying process. For biological samples are loaded into the critical point drying apparatus, the apparatus is then sealed, the pressure and temperature conditions are gradually increased to reach the critical point (temperature 31°C and pressure 1072 psi). Once the critical point is reached, the sample is held at this condition for a certain duration, this holding time period at the critical point is typically in the range of 30 minutes to a few hours, but it can vary depending on the specific requirements of the sample. After the hold time at the critical point, the system is depressurized to release the pressure gradually. This allows the carbon dioxide to transition back to a gas while avoiding abrupt changes that could cause sample distortion. The sample is dried by allowing the carbon dioxide to evaporate. This process should be gentle to prevent collapse or damage to the sample.

5. Mounting the sample on FE-SEM stub: Mount the dried sample onto a SEM stub using a conductive adhesive (carbon tape or silver paste or epoxy-resin or graphite paste). The carbon tape is a popular choice due to its electrical conductivity (to minimize charging effects during imaging), stability, and ease of use.

6. Sputter Coating Procedure: Sputter coating is a technique commonly employed before Field-Emission Scanning Electron Microscopy imaging, particularly when dealing with non-conductive or poorly conductive samples. The primary purpose of sputter coating is to apply a thin layer of conductive material (e.g., gold or platinum) onto the sample surface. This coating further enhances electrical conductivity and reduces charging effects. Sputter coating can enhance the emission of secondary electrons from the sample surface. This improvement contributes to better signal detection and increased image contrast in secondary electron imaging mode. Optionally, you can clean the sample surface from any residual contaminants using a gentle cleaning method, such as a plasma cleaner.

7. Mounting the sample stub on FE-SEM Stage: Carefully mount the prepared sample on the FESEM stage using appropriate holders or clamps, ensuring good electrical contact for conductivity.

8. Pump Down: Place the sample in the FE-SEM chamber and pump down to achieve the required vacuum.

9. Alignment and Focusing: Align the electron beam and focus on the region of interest. Optimize the electron beam parameters for high-resolution imaging.

10. Image Acquisition: Capture images at various magnifications and modes to obtain detailed information about the biological sample's surface structure.

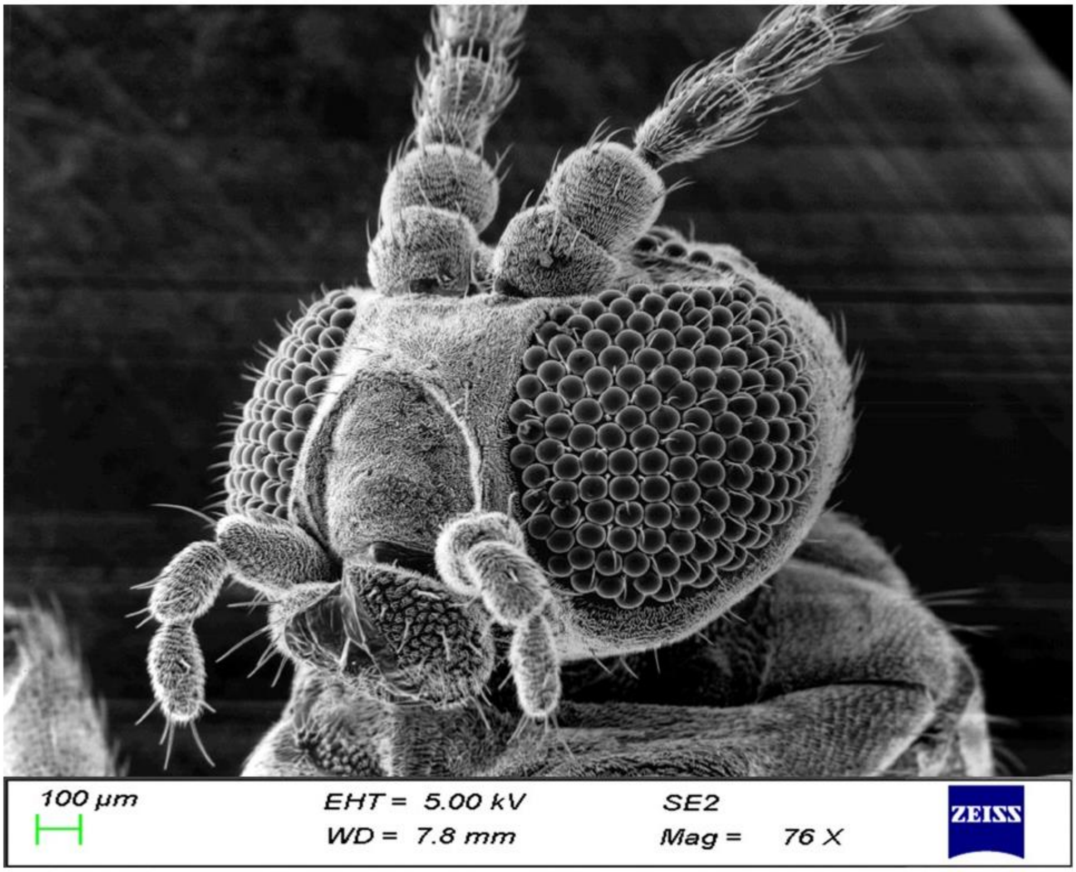

Figure 4. Image Acquisition: FE-SEM image of insect head

Application of FE-SEM in Life-Science Research:

Field-Emission Scanning Electron Microscopy (FE-SEM) is a powerful technique for high-resolution imaging of biological samples at the nanoscale. While there are various biological samples that can be studied using FE-SEM, the suitability depends on the specific requirements of the study and the sample preparation techniques used. Here are some common types of biological samples studied under FE-SEM:

Cell Morphology and Ultrastructure and Tissue imaging:

- **Cell Cultures:** Cells in culture, including mammalian cells, plant cells, and microbial cells, can be studied for morphology and structural details.
- **Tissue Sections:** Thin sections of tissues, prepared using techniques like microtomy, can be imaged to study the ultrastructure of tissues.

Microbial Imaging:

- **Bacteria:** Bacterial cells can be imaged to study their morphology, surface structures, and interactions.
- **Fungi:** Fungal structures, such as spores and hyphae, can be analysed for detailed morphological features.

Virus Particles:

- **Virions:** Individual virus particles or purified viral samples can be imaged to study their size, shape, and surface characteristics.

Cellular and Molecular Biology Studies:

- **Proteins and Protein Aggregates:** Protein structures, including amyloid fibrils and protein aggregates, can be visualized for structural analysis.
- **Nucleic Acids:** DNA and RNA structures, as well as nucleic acid complexes, can be studied.

Biological Nanostructures:

- **Membrane Structures:** Cellular membranes, including lipid bilayers, can be imaged to study membrane dynamics and organization.
- **Cellular Organelles:** Structures such as mitochondria, endoplasmic reticulum, and Golgi apparatus can be visualized in high detail.

Biological Materials and Composites:

- **Biological Composites:** Materials containing biological components, such as bone or tooth, can be imaged to study their microstructure.
- **Biological Nanoparticles:** Nanoparticles derived from biological sources, such as exosomes, can be imaged.

1. **Biological Surface and Interface Analysis:** Surfaces of biological samples, including biofilms, can be imaged to understand their structure and composition.
2. **Biological Nanoparticle Characterization:** Synthesized nanoparticles for drug delivery or diagnostic applications can be imaged for size, shape, and surface properties.
3. **Plant Morphology:** In plant science, FE-SEM is employed to study plant morphology at the cellular and tissue levels. This includes examining the structure of plant cells, trichomes, and other plant-specific features.

4. **Cancer Research:** FE-SEM is used to study cancer cells and tissues, providing insights into the morphological changes associated with cancer development. This aids in cancer diagnosis and understanding the underlying cellular alterations.

The high resolution and detailed imaging capabilities of FE-SEM make it an invaluable tool for life science researchers, enabling a wide range of studies from fundamental cell biology to advanced nanomedicine applications. Sample preparation techniques, such as fixation, dehydration, and coating, are crucial for obtaining optimal results in FE-SEM studies.

Discussion:

In essence, the introduction of the Field Emission Scanning Electron Microscope signifies a crucial moment in life science research. Its technological foundations, key features, and myriad applications have not only pushed the boundaries of microscale exploration but have also paved the way for new discoveries and a deeper understanding of the complexities of life at the nanoscale. As researchers continue to harness the capabilities of FE-SEM, it remains an indispensable tool propelling the field towards unprecedented advancements in knowledge and discovery. Despite its sophistication, FE-SEM demands meticulous sample prep with fixation, critical point drying, and sputter coating to preserve integrity. Conductive coatings on insulating samples prevent charging effects, showcasing its intricacy. In life science research, FE-SEM is invaluable, unravelling cellular intricacies with unprecedented detail. Its applications include studying cell morphology, tissues, microorganisms, visualizing virus particles, biomolecules, and nanostructures. The versatility of FE-SEM makes it crucial in cancer research, plant morphology studies, and investigations into biological nanoparticles.

The Field Emission Scanning Electron Microscope (FE-SEM) has transformed life science research, surpassing traditional SEM with its enhanced electron source. Utilizing a field emission electron gun, it produces a brighter and finer beam, achieving unparalleled precision at nano-meter levels. FE-SEM's increased resolution allows detailed imaging of fine structures, extending to higher magnification for exploration at atomic and molecular scales. Operating in a high-vacuum environment minimizes electron scattering, ensuring efficient imaging. This innovation represents a significant leap, pushing the boundaries of understanding in life sciences.

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Chapter- 16

Chemoresistance of Cervical Cancer Stem Cells: Challenges and Prospects

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Keywords: Cancer stem cells, Cervical cancer, Chemoresistance, Human papilloma virus (HPV), Self-renewal, Tumour microenvironment

Abstract:

Cervical cancer (CC) is one of the leading causes of death among women, with thousands of women diagnosed each year, particularly in developing countries where access to healthcare resources may be limited. Persistent infection with high-risk human papillomavirus (HPV) induces CC. While advancements in treatment modalities, such as chemotherapy, have improved outcomes for many patients, a significant challenge remains in the form of chemoresistance, particularly in the context of cervical cancer stem cells (cCSCs). cCSCs are a small subpopulation of cells within CC with self-renewal and aberrant differentiation capacity. Upregulation of biomarkers expression such as CD44, CD133, Sox2, ALDH1 and etc. is often associated with robustness of cCSCs. cCSCs possess higher invasion, metastasis and drug resistance ability thereby leading to poor prognosis and relapse. Therapeutic strategies to manage advanced CC typically involve surgery, radiotherapy and chemotherapy mostly using platinum-based drugs. However, acquired chemoresistance of cCSCs is the biggest challenge to therapeutic outcomes. There are several mechanisms involved in chemotherapy resistance in cCSCs, such as enhanced DNA damage repair mechanisms, which include nucleotide excision repair and homologous recombination, and promoting survival pathways like PI3K/AKT, Wnt, Notch. Elevated drug transporters like ABCG2 are one of the key feature for the resistance phenotype of cCSCs. Furthermore, epigenetic modulation and mutual interaction of cCSCs with tumour microenvironment play crucial role to avoid chemotherapeutic damage. This chapter aims to explore the mechanisms underlying chemoresistance in cCSCs and discuss potential therapeutic strategies to overcome this challenge.

Introduction:

Cancer stem cells (CSCs) are a small subpopulation of tumour cells with self-renewal and multilineage-differentiation potential like normal stem cells. CSCs maintain tumour heterogeneity and contribute to tumour initiation, progression, and recurrence. CSCs are mostly quiescent cells with higher invasion, metastasis and drug-resistance capacity leading to poor prognosis (Prasetyanti & Medema, 2017; Das et al., 2021). Several studies identified CSCs population by the expression of certain biomarkers, which are analogous to normal stem cells.

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The first CSCs population was isolated from leukemia with $CD34^{+}CD38^{-}$ expression. In solid tumour, CSCs were first identified in breast cancer ($CD44^{+}CD24^{-}$/lowLin^{-}), subsequently in brain, cervical, colon, pancreas, skin, lung cancers etc. (Saito et al., 2022).

Cervical cancer (CC) is the fourth most common gynaecological cancers and the second leading cause of death among women after breast cancer. CC are mostly induced by persistent human papillomavirus (HPV) infection, which is typically asymptomatic. Recent advancements of cytological screening and vaccination programs reduced the occurrence rate of CC at early stage (Burmeister et al., 2022). Advanced CC cases are normally treated using a combination of radiotherapy and chemotherapy. However, it remains a significant global health challenge, with chemoresistance posing a major obstacle to successful treatment. Even though many drugs, most importantly platinum-based drugs are used to treat CC, however, acquired chemoresistance lead to relapse (Zhu et al., 2016). Therefore, it is very important to understand the molecular mechanism of chemoresistance for developing CC treatments. Recent research has shed light on the role of CSCs in driving chemoresistance, offering new insights into potential therapeutic strategies. The heterogeneity of CC is achieved by the existence of cervical CSCs (cCSCs). Therapeutic targeting of cCSCs has the ability to reduce metastasis and relapse by preventing the generation of new CC clones (Huang & Rofstad, 2017). This chapter aims to provide an update on the role of cCSCs and the molecular mechanisms involved in therapy resistance.

Epidemiology and risk factors of cervical cancer

Globally, cervical cancer accounts for an estimated ~604,127 new cases and 341,831 deaths in 2020 (Singh et al., 2023). It displays higher incident rates and ~90% mortality in low and middle-income countries specifically in Sub-Saharan Africa, Central America and South-East Asia (Hull et al, 2020). CC is the second most common cancer among Indian women, accounting for ~17% of all female cancer cases. An estimated 96,922 new cases and 60,078 deaths from cervical cancer were reported in India in 2020, highlighting the substantial burden of the disease (Singh et al., 2022). CC incidence varies across India, with higher incidence and mortality rates observed in rural areas. CC predominantly affects women in their reproductive years, with peak incidence observed between the ages of 35 and 55 years. Disparities in cervical cancer incidence and mortality are closely linked to socioeconomic factors, including access to healthcare services, education, and poverty levels. Lack of access to screening programs including Pap smears and HPV testing, vaccination, and timely treatment, contribute to higher mortality rates in underserved populations (Singh et al., 2022).

The primary causative factor for CC is the persistent infection with high-risk HPV types, particularly HPV-16 and HPV-18, accounting for nearly all cases. However, co-infection with human immunodeficiency virus (HIV) or any other immunosuppression adds up to the risk of HPV acquisition and cervical cancer development. Other risk factors for cervical cancer include first sexual encounters at early age, multiple sexual partners, prolonged use of oral contraceptives, smoking, cervix dysplasia (Chan et al. 2019).

Although most of the HPV infections are transitory and cleared spontaneously by the immune system, ~95% of malignant CC are resulted from high-risk HPV infection. Carcinogenic HPV (HPV 16 and 18) infected cells arise in the transition area between the exocervix and endocervix, which is known as the squamocolumnar (SC) junction, eventually lead to cervical intraepithelial neoplasia (CIN, ~90%) and carcinomas (Sravani et.al, 2023). CC are categorized primarily into two histological subtypes- Squamous cell carcinoma (70%) and adenocarcinomas (25%). Other less common types of CC include adenosquamous, small cell or neuroendocrine, serous papillary and clear cell carcinomas. These specific SC junction cells express junction-specific markers like CD63, anterior gradient 2, matrix metalloproteinase 7 and guanine deaminase. It has been hypothesized that CC develops from stem-like cells in the transition area of the cervical opening in the presence of the persistent infection with hrHPVs (Zhang et al., 2020).

Current management strategies for cervical cancer

Pap smear screening and HPV testing have been effective for the early detection of lesions in the cervix which lower the incident rate and mortality in high-resource countries. The immune system clears most of the early precancerous lesions, however, due to persistent hrHPV infection and having a weakened immune system lead to the progression of lesions into invasive cancer. Detection stages of CC by the International Federation of Gynaecology and Obstetrics (FIGO), is the most prognostic factor in order to plan the best treatment (Bhatla et al., 2018). Depending on the extent of the disease these patients are treated with cryotherapy, laser therapy, or loop electrosurgical excision procedure. Cryosurgery and laser surgery are applied to remove precancerous lesions (Khan et al., 2014). The early-stage CC (stage Ia1-Ib1) can also be successfully treated by primary surgery with 5-year survival rates of 85-95%. However, nodal metastasis, parametrial extension in early stage has significant risk of local relapse after primary radical hysterectomy. Locally advanced CC (stage Ib2-IVa) are usually prescribed with chemoradiotherapy and the death rate for these patients with lymph node metastasis has been improved by the addition of chemotherapy to the radiotherapy protocols. Radiation therapy (RT) is used in the treatment of non-metastatic CC to reduce the size of the tumour or to halt the growth of the cancer cells that remain after the surgery (Martin-Hirsch & Wood, 2011). In chemotherapy, the use of platinum-based drugs is the primary therapeutic option for advanced and recurrent cervical cancer. Cisplatin is a commonly used drug which covalently binds to DNA and induces cell cycle arrest, inhibits replication thereby leading to DNA damage and eventually apoptosis. In addition, cell cycle-specific drugs, including paclitaxel, vincristine, and 5-fluorouracil, have radiosensitization capabilities or synergize the cytotoxic effects of platinum drugs (Duenas-Gonzalez et al., 2019). However, chemoresistance remains a formidable obstacle in the treatment of cervical cancer, particularly in the context of cervical cancer stem cells (cCSCs).

Cervical Cancer Stem Cells

The traditional "clonal evolution" theory of carcinogenesis, proposes that CC arises due to a mechanism of uncontrolled and unlimited cellular proliferation in cells of clonal origin within a tumour, there is genetic heterogeneity in CC. Another theory suggest that the intratumoural genetic heterogeneity in CC is due to the existence of cervical cancer stem cells (cCSCs). cCSCs represent a small subpopulation of cells within cervical tumours that possess self-renewal capabilities and the capacity to differentiate into heterogeneous tumour cell populations. These cells are implicated in tumour initiation, progression, lymph node metastasis, poor response to chemo/radiotherapy, and pelvic recurrence, making them a critical target for therapeutic intervention (Di Fiore et al. 2022). Recent studies suggested that, the ability of CSCs to transdifferentiate into vascular endothelial cells and other tumour-associated stromal cells contribute to the heterogeneity of tumour (Huang et al., 2015).

Cell surface markers such as CD44, CD 24, CD 49f, and CD 133 have been used to identify cervical cancer stem cells. Pluripotent transcription factors, for example, Sox2, Oct3/4, Nanog have been widely used to isolate and enrich CSC populations from different tumours including cervical cancer. Higher level of aldehyde dehydrogenase 1 (ALDH1) is also considered as an indication of stemness properties. High-risk HPV induces cervical carcinogenesis due to the overexpression of the viral oncoproteins E6 and E7 which in turn upregulates expression levels of stemness associated genes such as Oct3/4, Sox2, Nanog and fibroblast growth factor 4 to maintain the self-renewal capacity of CSCs. CSCs contribute to the tumourigenic potential of cancer and resistance to cytotoxic drugs and ionizing radiation leading to relapse (Organista-Nava et al., 2019). Understanding the underlying mechanisms driving chemoresistance in cCSCs is crucial for the development of effective therapeutic strategies to overcome this challenge. Here, we discussed the detailed mechanisms therapeutic resistance of cervical CSCs.

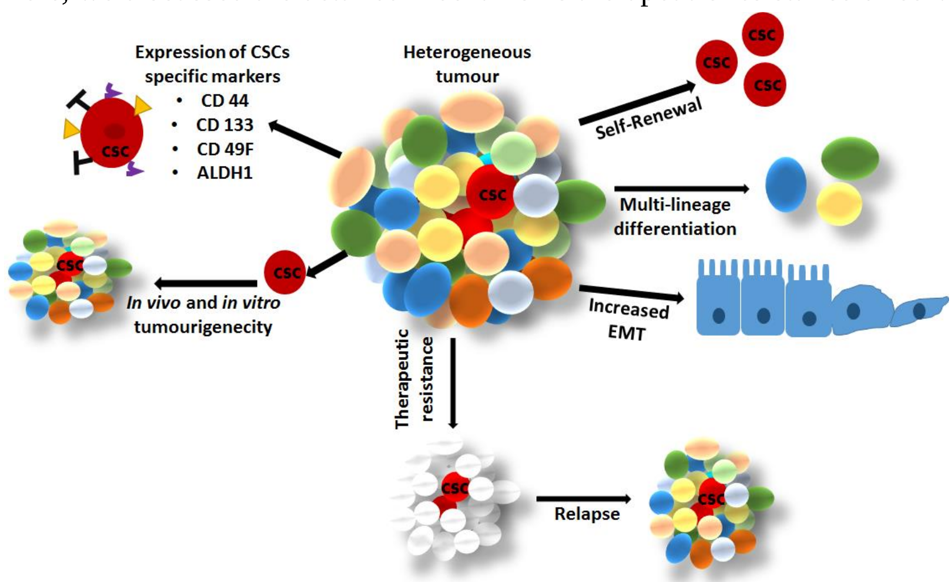

Figure 1. Properties of cervical cancer stem cells (cCSCs)

Mechanisms of therapeutic resistance of cCSCs

Cytotoxic anti-cancer therapies for CC involve both the combination of radiotherapy and chemotherapeutic drugs, such as platinum-based drugs, antimetabolites, or anthracyclines. Radiotherapies and certain chemotherapeutics induce cytotoxicity by means of direct DNA damage. Other group of chemotherapy such as paclitaxel, is the mitotic spindle poisons, and their mechanism of action is to exert toxic effects on the dynamics of microtubules thereby inhibiting cell division. Therapy resistances have been linked to CSCs and is considered one of the main possible causes of poor results for cervical cancer and other malignancies (Bailly et al., 2020). Thus, through the understanding of different cellular as well as genetic mechanisms involved in the development of treatment resistance by which the CSCs escape chemotherapy and radiotherapy, more effective treatments can be developed for CC.

Enhanced DNA Repair Mechanisms:

Radiation and some chemotherapeutic drugs trigger the DNA damage response which leads to cell cycle blockade followed by induction of apoptosis in sensitive cervical cancer cells. However, cCSCs exhibit upregulation of several DNA Damage Response (DDR) genes with roles in different DNA repair pathways, including nucleotide excision repair and homologous recombination, conferring resistance to DNA-damaging agents such as cisplatin. Radioresistant CSCs exhibited upregulation of homologous recombination (HR) gene such as RAD51 and HR/single-strand annealing pathway gene- RAD52 (Zhou et al. 2021). DNA damage sensor proteins, such as ataxia telangiectasia mutated (ATM) and ataxia telangiectasia mutated-RAD3-related (ATR) kinases form complexes with breast cancer 1 (BRCA1) and poly ADP-ribose polymerase (PARP-1) and promote DNA repair capability of cCSCs through CHK1/CHK2 phosphorylation or by activating anti-apoptotic signalling pathways, such as PI3K/Akt, WNT/β-catenin, and Notch signalling pathways (Marzagalli et al., 2021). Non-homologous end-joining genes like XRCC2 and Ku70/80, and genes related to reactive oxygen species (ROS) metabolism such as CYBA2 and SOD2 are also found to be upregulated in cCSC. Radio-resistant cCSCs with higher aldehyde dehydrogenase (ALDH)-1 activity exhibit preferential activation of the DNA damage checkpoint response and protect cells from elevated levels of ROS. Some studies have interconnected splicing/ RNA-binding proteins (RBPs) to the DDR response and CSC biology. The expression of the RBPs such as TRA2α/TRA2β which regulate CHK1 expression, are associated poor prognosis in cervical cancer. Transcriptomic data of cervical cancers also showed increased expression of SRSF6, an RBP gene, compared to normal tissues which corresponded with an increase in alternative splicing of DDR genes. SRSF1 binds to and stabilizes RECQL4 mRNA, a master regulator of genome stability, through regulating DNA replication and multiple DNA repair pathways (Gillespie et al., 2023).

Altered Drug Efflux Pumps:

Analysis of side population cells through flow cytometry is one of very popular methods to identify and isolate CSCs in different solid tumours, including CC. Overexpression of drug-transporter proteins, including multidrug resistance (MDR) proteins of ATP-binding cassette (ABC) transporters family such as ABCB1 (P- glycoprotein), ABCC1, and notably ABCG2, facilitates the efflux of chemotherapeutic agents, reducing intracellular drug accumulation in cCSCs (Alisi et al., 2013). This enhancement of MDR proteins is one of the main protective mechanisms for CSCs in response to chemotherapeutic agents which facilitates the expulsion of cytotoxic drugs leading to higher resistance to chemotherapeutic agents and disease relapse. ABC transporters blocker such as fumitremorgin C and verapamil, have been used in ovarian cancer to sensitize CSCs (Di Fiore et al., 2022).

Activation of Survival Pathways:

Activation of PI3K/Akt and MAPK/ERK signalling pathways in cCSCs promotes cell survival and anti-apoptotic responses following chemotherapy-induced stress. P21-activated kinases (PAKs; serine/threonine kinases) have pivotal roles in tumour progression by regulation of the Ras-induced metabolism, cell proliferation, angiogenesis, and EMT (Navaei et al., 2022). Studies have showed that PAK4 is significantly upregulated in cervical cancer tissue samples which is involved in cancer progression and promotes the cisplatin through PI3K/AKT pathway. Secreted phosphoprotein 1 (SPP1) upregulation has been observed in cervical cancer tissues and suppression of SPP1 inhibited of PI3K/AKT pathway thereby reducing cisplatin resistance (Shu et al., 2015). Stem cell regulatory pathways such as Wnt/β-catenin, Hedgehog signalling, Notch signalling, and TGF β pathways are often upregulated in cervical CSCs and are associated with cancer progression, metastasis as well as therapy resistance (Manni et al., 2022).

DNA methylation:

Epigenetic mechanisms are key regulators of CSCs. DNA methylation helps cancer cells to regain stem CSC-specific features. Alteration of methylome profile can contribute to the progression and therapy resistance of CSCs. Consequently, agents targeting epigenetic programming such as DNA methyltransferase (DNMT) inhibitors are a class of potent anti-CSC compounds that are already being used in CC. Aberrant methylation of apoptotic signalling genes such as death-associated protein kinase (DAPK), and tumour necrosis factor receptor superfamily member 6 (FAS), results in acquired resistance to radio- and chemotherapy. The promoter hypomethylation of cancer/testis antigen gene, CAGE, results in cell cycle progression, angiogenesis, and drug resistance (French & Pauklin, 2021).

Epithelial-Mesenchymal Transition (EMT):

The epithelial-to-mesenchymal transition (EMT) is a reversible process, by which epithelial cells can convert into a mesenchymal phenotype, with altered expression of polarity, adhesion molecules, and morphology of cells. EMT activation is associated with metastasis, and treatment resistance by inducing cancer cells to exhibit stem cell-like features, which promote invasion of surrounding tissues and the underlying drug resistance. However, in most cases, the molecular mechanisms of EMT transition and EMT-associated therapeutic resistance in CC are not clear. EMT transcription factors, such as SLUG, SNAIL, and TWIST can confer stem-like features in cancer cells (Phi et al., 2018). Study reported that, in cervical cancer, TGF-β/Smad3 pathway activation by TWIST induces EMT (Fan et al., 2015). Chronic treatment of epidermal growth factor (EGF) increases the expression of fibronectin, a mesenchymal marker. In cervical cancer treatment with EGF induces mesenchymal phenotypes. In cervical cancer, EMT increases the CSC subpopulation and leads to chemoresistance and radio-resistance. Hence, inhibiting epithelial to mesenchymal transition in CC cells sensitizes them to drugs and radiation (Qureshi et al., 2015).

Tumour Microenvironment Interactions:

The tumour microenvironment (TME) comprises of tumour cells and several non-cancerous cells like fibroblasts, stromal cells, endothelial cells, immune cells (such as macrophages, microglia, and lymphocytes), as well as the constituents of extracellular matrix. The interaction between TME and cancer cells is crucial for the establishment of a CSC niche which supports quiescence property and promote tissue invasion. Highly angiogenetic cancers like advanced CC, CSCs can differentiate into functional endothelial cells to form blood vessels known as vascular mimicry (Di Fiore et al., 2022). Angiogenic factors released from CSCs promote vascular growth and enhance tumour growth. On the other hand, endothelial cells provide angiocrine-signalling to regulate CSC behavior. Interactions between cCSCs and components of the tumour microenvironment, such as cancer-associated fibroblasts, tumour-associated macrophages, and extracellular matrix proteins, create a protective niche that shields cCSCs from the cytotoxic effects of chemotherapy. The microenvironment could stimulate signalling pathways, such as Notch and Wnt and create an inequity between self-renewal and differentiation CSCs. These disproportion enable CSCs for higher evasion, metastasis and anoikis (Phi et al., 2018; Madhu et al., 2022, 2023).

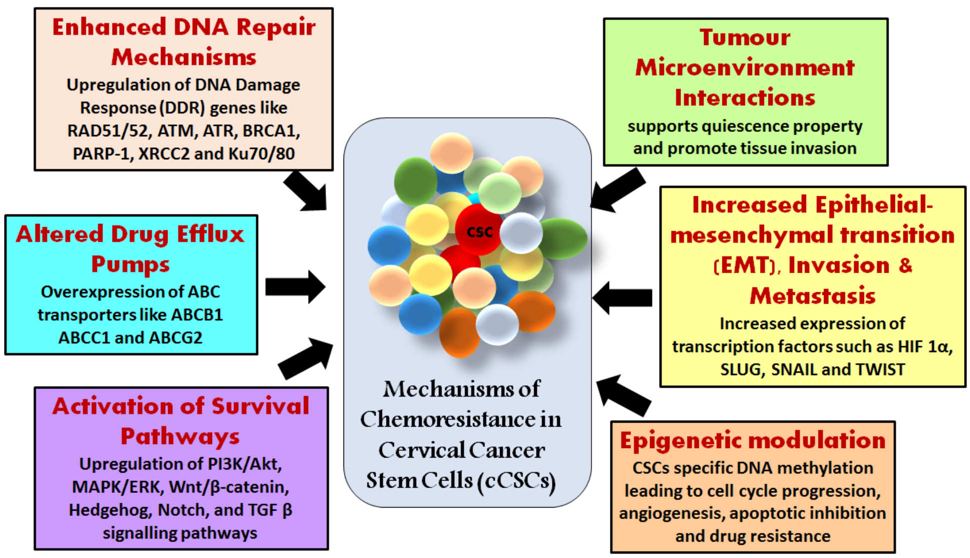

Figure 2. Mechanisms of chemoresistance in cervical cancer stem cells (cCSCs)

Hypoxic TME is associated with increased cancer aggression, progression, metastasis and significantly impair tumour response to anti-cancer therapies. Hypoxia-inducible factors 1 and 2 (HIF1/2) are activated in hypoxic TME which bind to promoter regions containing the hypoxia-response element (HRE) of several downstream genes associated with angiogenesis, apoptosis, metabolic regulation, and pH balance. Activated PI3K/ATK pathway further activate HIF1/2 creating a feedback loop to promote CSCs (Heddleston et al., 2010). Studies have shown that hypoxia promotes radioresistance of cCSC from HeLa and SiHa cell lines by activating the DNA damage checkpoint response and improved DNA repair (Yao et al., 2020).

Targeting cervical CSCs to overcome chemoresistance

CSC-targeted therapy has been a popular topic for research in past few years to improve and prevent cancer relapse. However, very few studies related to cCSC-specific targeted therapies have been carried out so far. In general, strategies combining conventional chemotherapy with molecules targeting cCSC-specific pathways such as Notch, Wnt, Hedgehog, hold promise in overcoming chemoresistance. Inhibition of key stemness regulatory molecules like Oct4, Sox2, and Nanog has been shown to sensitize cCSCs to chemotherapy and reduce tumour recurrence (Huang & Rofstad, 2017). As previously mentioned, ALDH protects cCSCs from elevated ROS levels and promotes chemo-and radio-resistance. Several ALDH inhibitors such as CM307 and 673A have shown efficacy in pre-clinical models of gynecologic malignancies, therefore, have potential for improving patient outcomes in CC (Muralikrishnan et al., 2020). The inhibitors of ABC transporter in combination with chemotherapy is in pre-clinical study in CC (Shukla et al., 2011). Nanocarriers loaded with chemotherapeutic agents can enhance drug delivery to cCSCs while minimizing systemic toxicity. Gold and silver nano-particles conjugated with chemotherapeutic agents showed efficacy against human glioma, breast cancer and oral cancer stem cells in vitro. Harnessing the immune system to target cCSCs via immune checkpoint inhibitors or chimeric antigen receptor (CAR) T-cell therapy represents an emerging approach in combating chemoresistance (Huang & Rofstad, 2017). Disrupting interactions between cCSCs and the TME through targeting ECM remodelling enzymes, immune checkpoint inhibitors, and CAFs may enhance the efficacy of chemotherapy. Therefore, combinatorial approaches incorporating conventional chemotherapeutic agents with targeted therapies, immunotherapy, or epigenetic modifiers hold promise for overcoming chemoresistance and improving treatment outcomes in cervical cancer patients. There are also certain limitations for CSC-targeting therapies. CSCs are usually present at very low in numbers (0.1-10%) and their biological characteristics are quite similar to normal stem/progenitor cells, therefore, making the task more challenging to specifically target CSC.

Conclusion:

Understanding the molecular mechanisms underlying chemoresistance in cCSCs is crucial for the development of effective therapeutic strategies. Targeting cCSC-specific pathways, utilizing nanotechnology-based drug delivery systems, modulating the tumour microenvironment, exploring combination therapies, and exploring immunotherapeutic approaches offer promising avenues for overcoming chemoresistance and improving outcomes in cervical cancer patients and reduce the burden of cervical cancer worldwide.

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Chapter- 17

Wetland Ecosystem and Socio-Economics: Interdependence for Sustainability

Susmita Lahiri*, Sanjukta Mistri, Sanjana Lahiri and Ashis Kumar Panigrahi

Keywords: wetlands, ecosystem, economy, sustainability, interdependent

Abstract:

Recent advances in environmental research have proved that wetlands are the most promising solution in controlling and managing environmental problems, with their unique property of enormous diversification in spatial, creation, water and sediment characteristics, and keystone species. While providing the natural habitat and breeding ground for about 40 percent of global wildlife, they also serve as vital sources of genetic medicinal resources, hydropower, food, raw materials and ecological services of flood mitigation, coast embankment protection and community resilience against disasters. The versatile study of wetland ecosystems and their contribution to large-scale environmental protection was undertaken by many scientists, and the concept progressed through numerous studies, mainly for tropical developing countries rich in wetlands like India. Their environmental importance was given global recognition at Ramsar convention held in 1971 where the wetland characteristics and functions were precisely defined along with the recommendations for wise use and its resource conservation in order to achieve sustainable development. Irrespective of variable sizes, wetlands' ecological and economic valuation is similar in significance and uniqueness. Because their services can be considered non-market goods, their economic valuation should be in monetary terms to get long-term benefits from investment upscaling for conservation. Wetlands also function as a unique, well-established system of waste treatment, recycling and resource recovery when the nutrients from waste are reused into fish culture and agriculture. The present environmental degradation of the system is affecting the livelihood of poor people who depend on the local wetlands. A model-based interactive approach will not only measure the interdependencies of the current situation of the ecological and social vulnerabilities but also will be able to predict future changes, thus bringing about sustainability.

Introduction:

Ecologists can never separate the functional attributes of a wetland ecosystem from its production potential and hence termed this ecosystem as 'valuable and productive' ecosystem in the world due to their effective and important services to human society. Their rich and high

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environmental production is due to their wide array of roles from the most efficient cradle of biological diversity to a global environmental ‘stabilizer’, ‘filter’, ‘sink’ ‘flood control’ etc. Economically, wetland services have a five times higher total economic value than tropical forests (Maltby and Acreman, 2011). Scientists and environmentalists worldwide are focusing more on the study of wetland ecosystem due to their rapid conversion due to human greed and need that prevents sustainable development. 1 billion people, depends on wetlands for their livelihood, making the wetland ecosystem a valuable and productive ecosystem in the world (Baral et al., 2016; Costanza et al., 1997; Mitsch and Gosselink, 2000).

Ramsar Convention was signed in 1971 at Ramsar, Iran which decided on the wetland conservation and its sustainable use. ‘Wetland Health Card’ has been decided to be issued by environment ministry to monitor the entire wetland ecosystem based on multiple parameters (The Economic Times, 2019). Concern for the wetland carrying capacity acts as a major challenge for sustainable development since it affects human life's social, political, and economic conditions (Costanza et al., 1993; Bassi et al., 2014). A meaningful sustainable development can be ensured with a proper analysis of the interrelationship and interdependency between ecological services and economic return.

Materials and Methods:

Nearly 500 research literature pertaining to research articles, review, short-communications, book-chapters, news-reports were reviewed for the collection of information on the title. Mostly peer-reviewed literature was consulted. The keywords used were wetland-ecosystem, sustainability, economics, wetland-degradation. The search engines employed were GoogleScholar, Researchgate, Pubmed, Scielo, CiteSeer X, SciTech Connect etc. After screening the papers, most relevant papers were finalised and the search results were categorised into the following groups.

Major Ecological Functions

Kidney of landscape

The filtering function of kidney is well exhibited by the wetlands which can absorb, dilute and transform nutrient wastes, suspended solids coming from adjoining terrestrial ecosystems by removing them from surface, thus filtering the pollutants and contaminants. Physical processes of sedimentation, sorption along with microbial nutrient transformations (Ramachandra and Aithal, 2015) and uptake by wetland vegetation (Fig-1) are primarily responsible for filtration activity. *Pistia stratiotes* could remove 70% ammonium and 59% total-nitrogen (Prajapati et al., 2017). 77%, 60% and 68% removal of TSS, nitrate-nitrogen and *E. coli* (Vymazal, 2007) respectively have been reported.

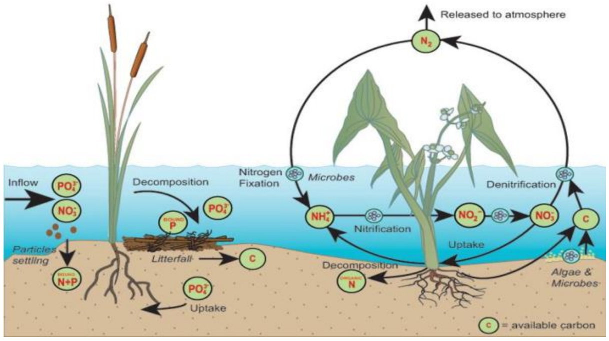

Figure 1.The kidney function of wetlands (modified from Kadlec and Knight (1996)

This pollutant filtering function of wetlands has been effectively used for the treatment of municipal and industrial wastewater by constructing artificial wetlands (Mitsch and Gosselink, 1993, Almuktar et al., 2018), the design of which has been upgraded to include many combined-hybrid models (Marzec et al., 2018). Aquaculture practice in wetlands has also induced the pollution removal process mainly through microbial-biogeochemical transformations (Ganguly et al., 2015; Lahiri et al., 2017). Livelihood through sewage-fed aquaculture is generated by implementing systems-ecology and employing ecological engineering techniques (Jana, 1998). Constructed wetlands can also efficiently remove cadmium while utilizing the organic waste for fish culture (Rana et al., 2011).

Biological supermarkets

Wetlands are rich in biotic diversity, providing unique habitats and extensive food-webs for a diverse range of plant and animal species. Enormous photosynthesis and nutrient recycling activities by the intricately diversified taxonomical wild living system can shape the uniqueness of wetland ecosystem. Besides serving as a food resource obtained from detritus, wetlands provide breeding and life-cycle habitats for many animals (Sandilyan et al., 2010) and help the weaker species hide from predators due to thick wetland vegetation.

Carbon sequestration

Sediments of tropical or sub-tropical swamps, mangroves, peatlands and marshes are a rich sink of carbon(Mitsch et al., 2013), storing nearly 20-30% of Earth's soil pool (Lal, 2009) and is suitable for carbon trading and climate change mitigation. Because of high organic matter, restricted decomposition and anoxic wet conditions, wetland soils (Fig-2) have sequestered 0.4 tonnes C/ha/year over 50 years. Sourcing 40% of global methane emission (Bloom et al., 2010) due to prolonged nutrient loading, the balance of CH_4 and CO_2 exchange can provide a global warming potential index.

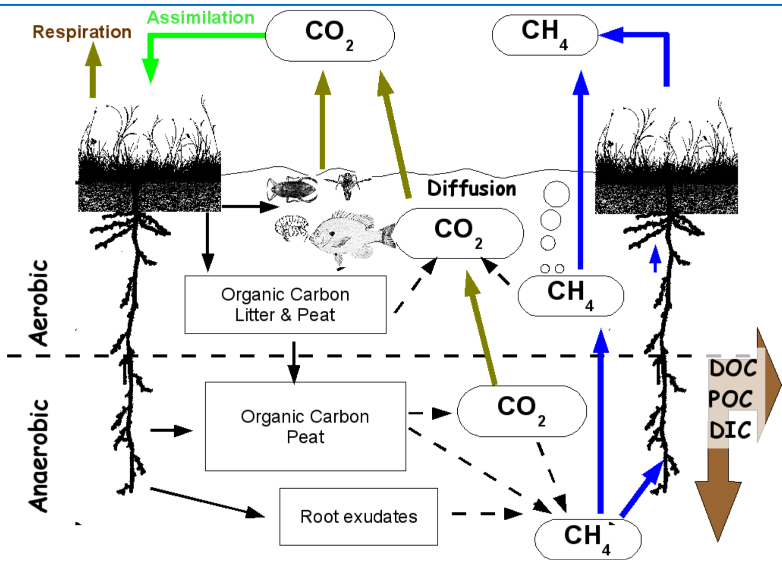

Figure 2.Carbon cycle helping in carbon sequestrationin wetlands (Van der Valk, 2006)

Flood Control

Trees, vegetation and root spread of wetlands regulate stream flow by trapping and slowly releasing the flood waters (Rafiq et al., 2014) resisting large-scale erosion and dredging expenses. Further, their sponge character provides hindrance to the direct flow of suspended particles and nutrient load into rivers. Many characteristics of wetlands such as location, configuration, topography, soil structure and quality, influence the flood control function (Acreman and Holden, 2013).

Wetland ecosystem at risk

Despite a strong early bond between wetland and human communities, wetland conversion for non-wetland uses has been increasing historically. Since 1970, 35-50% of global natural wetlands no longer exists (Ramsar Convention, 2018) which is an alarming trend.

Major direct drivers are infrastructure advancement, land-conversion, excessive water-extraction, harvesting, pollution and eutrophication stress and invasive alien species introduction (MEA, 2005). Megatrends include climate change (Bates et al., 2008) and changing consumption patterns of enhanced land and water use (Kumar, 2013). Moreover, wetland siltation due to these stressors further alter the biological communities (Masese et al., 2012).

Alteration of carrying capacity of wetlands affects the positive and negative feedback mechanisms of the wetland ecosystem which act as the critical control systems (Gökçe, 2019) of the wetland ecosystem dynamics (Fig-3), thus achieving a non-steady state (Soto-Ortiz, 2015).

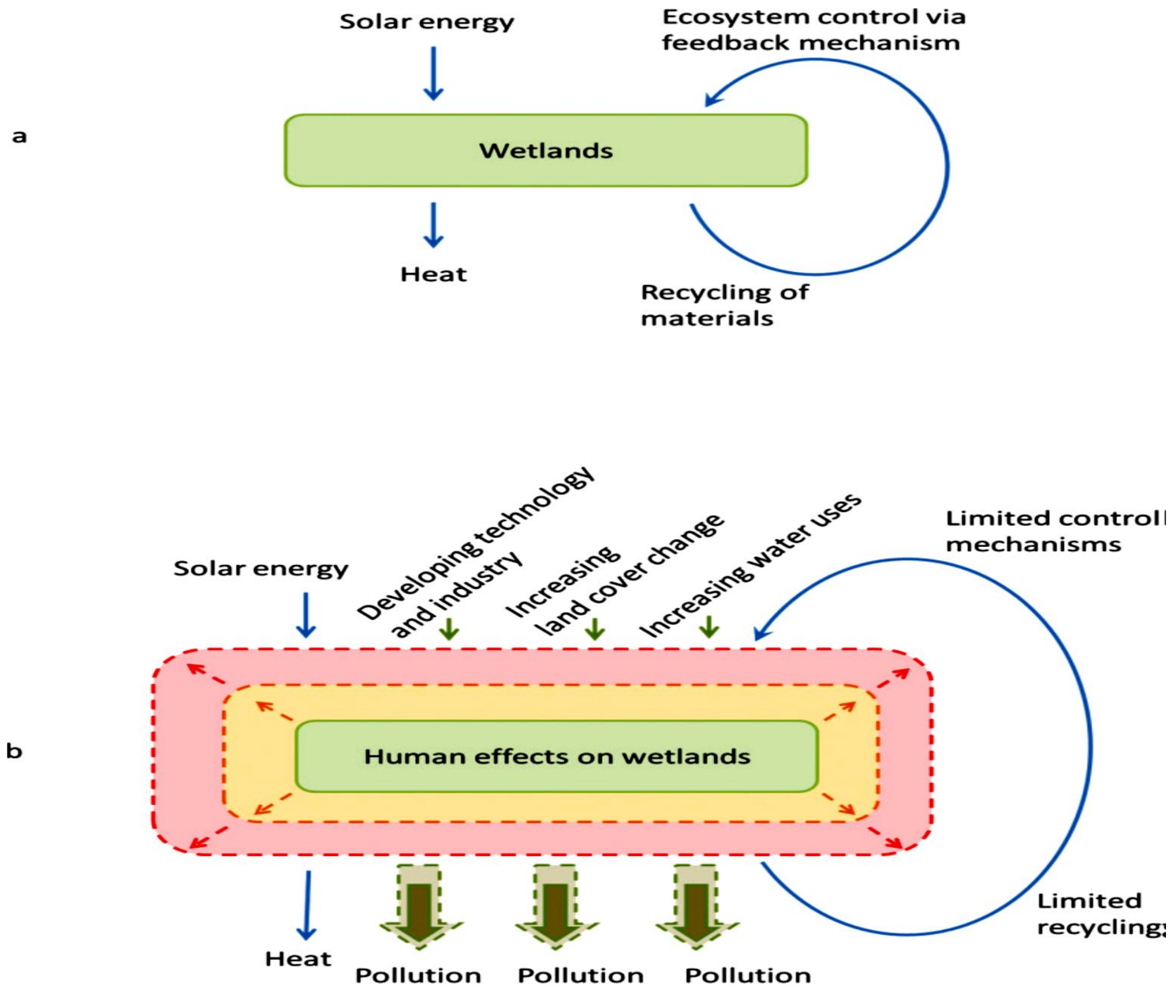

Figure 3.Wetland ecosystem dynamics (Gökçe, 2019)

Asia is the most affected area in comparison to its European and North American counterparts due to indiscriminate deterioration of water quality and widespread eutrophication.

In India, particular wetlands are considered as 'wastelands' by many decision-makers due to their easy accessibility for extraction without any imposed price. Moreover, water quality gets seriously degraded due to reduced inflows, pesticides runoff and sink for untreated effluents (Brinkman et al., 2020). The rapid change in land use and landcover due to fast urbanization is also decreasing India's wetland area, leading to a complex social–ecological transformation process.

Wetland Conservation and Management

Ramsar Convention as early as in 1971 ensured wise-use of wetlands for its 'sustainable utilization for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem'. National Environment Policy (NEP), 2006, Wetland Conservation and Management Rules, 2017 were framed as a regulatory measure for protection of wetlands of India. Very recently, a notification prohibited setting up or expanding industries and disposal of construction and demolition waste within the wetlands.

In order to make this change temporary an ecosystem based management approach striking an appropriate balance between wetland conservation and socio-economic development can be the best option (Maltby, 2006). Wetland ecosystem indices offer a comprehensive framework for identifying, organizing, and analyzing the intricate factors that impact wetland ecosystems' living and non-living components. McCartney et al. (2005) developed the Working Wetland Potential (WWP) index, which utilizes a multi-criteria analysis to integrate wetland utilization's biophysical and socio-economic aspects. The conservation strategy may also involve activities such as wetland mapping and delineation, creating databases for temporal, spatial, and non-spatial information, establishing bodies for water quality monitoring, and conducting ecological health monitoring and socio-economic dependence analysis.

Wetland economic importance and assessment

Wetland valuation groups

Actual planned and possible use of wetlands by humans is designated as use-value in a Total Economic Valuation scheme whereas the unplanned, non-human interactive use gives non-use values (Tuan et al., 2008). Use-value is further grouped into direct and indirect use values which both together can be option value. Non-use-values can be existence, quasi and bequest values.

Direct values: Widely known common services of wetlands used for direct consumption, sale, production, livelihood generation such as fish harvesting (Neiland, 2008), fuelwood collection, providing shelter, transport, water supply, agricultural crops (Emerton, 2016), recreation and other commercial and non-commercial activities in developing countries or for sport and recreation in developed countries (Barbier et al., 1997) are designated as direct values. Nearly 50% of a family's total income in a Zimbabewan village comes from direct use of wetlands (Mahlatini et al., 2020).

Indirect values: Wetland function-dependent uses have been valued to protect and maintain the balance of nature and the human system. The functional network is woven with ecological importance.

Option value: This includes uncertainty about future demand for wetland resource and/or availability.

Existence values: The inherent worth of wetland ecosystems and their constituent elements, irrespective of their present or potential utilization prospects – encompassing cultural, spiritual, aesthetic, and heritage importance.

Quasi-option value: The anticipated worth of the knowledge obtained from postponing the present wetland's utilization and transformation (Pascual et al., 2012).

Bequest values: Individuals who prioritize conserving tropical wetlands for future generations.

Considering the economic potentiality of ecological services of wetlands (Maltby et al., 2013) to human life, its valuation is based on non-market site-specific property based techniques (Table-1).

Table 1: Valuation methods of wetland services (Barbier et al., 1997)

Method	Applicable to	Description and importance
Market price method	Direct use values, specialty wetland products.	The value is estimated from the commercial market(law of demand and supply)
Damage cost avoided. Replacement cost or Substitute cost method	Indirect use values: coastal protection, avoided erosion, pollution control, water retention.	The cost of constructing and operating a water treatment plant can provide an estimate of the value of removing organic pollutants or any other pollutants. Similarly, the potential damage costs avoided in the event of flooding can help estimate the value of flood control measures.
Travel cost method	Recreation and tourism	The recreational value of a site can be determined by the amount of money individuals invest in visiting the location.
Hedonic pricing method	Future use and Non-use values.	This approach is employed when the value of wetlands impacts the cost of goods being sold. The presence of clean air, expansive bodies of water, or picturesque vistas will enhance the value of residential properties and plots of land.
Contingent valuation method	Tourism and non-use values.	One effective approach to estimate the Non-use values is by directly questioning individuals about their willingness to pay for specific environmental services. This method, known as the "stated preference method," is frequently employed as it allows for a more accurate estimation.
Contingent choice method	wetland goods and services	Estimate values by soliciting individuals to make tradeoffs among various sets of ecosystem or environmental services.
Benefit transfer method	General ecosystem services and recreational use	Economic values are estimated by applying benefit estimates from previous studies conducted in different locations or contexts.
Productivity method	For specific wetland goods and services; water, soil, air-humidity.	Calculates the monetary worth of wetland resources or benefits that contribute to the manufacturing of goods sold in the market.

Wetland economic assessment

Increasing exploitation and degradation of wetlands has an adverse impact on its economic values and so a number of economic assessment methods used by different economists has been synthesized to form an integrated wetland economic assessment framework. It involves analysis of wetland functions, policy and stakeholder along with wetland service valuations. The outcome needs to be communicated to all stakeholders and decision makers. Additional activities of expert consultation, multi-function use, total economic valuation and environmental impact assessment form the part of policy analysis. For management and policy measures, cost-benefit analysis, multi-criteria analysis need to be applied as component of trade-off analysis.

The economic assessment methodology calculates the option of wetland to either maintain its natural condition or undergo degradation or conversion to a different purpose, resulting in the acquisition or loss of certain values. Wetland values are frequently overlooked or undervalued in decision-making processes, resulting in degradation or complete destruction of these vital ecosystems (Dutta et al., 2014).

Wetland ecosystem *vs* socio-economics

The linkage between social and ecological systems (Masi et al., 2018) is of various types, which may be synergistic and co-evolutionary (Fig-4).

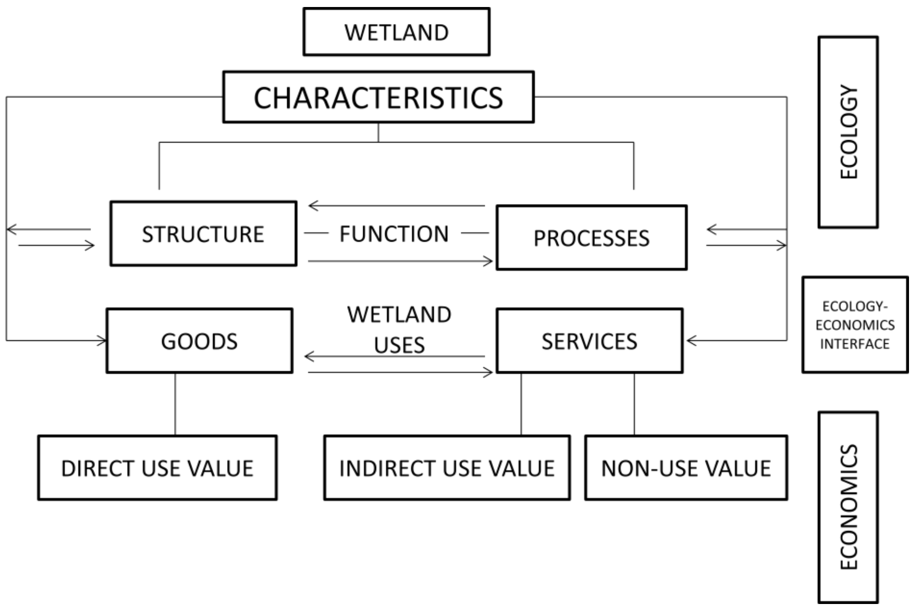

Figure 4. Ecology-economics interface of the wetland uses

However, any damage to the environment results in social vulnerability when people get exposed to that environmental stress. This may vary according to the human capacity to cope with the stress (Dey and Banerjee, 2018).This gives rise to the phenomenon of 'environmental criticality' referring to circumstances where the degree or speed of environmental decline prevents the maintenance of existing utilization methods or standards of human welfare, taking into account possible adjustments and societal capacities to react (Patra & Madhu, 2009). This social vs ecological conflict may be caused by overlooking certain cultural contexts and local technical knowledge while considering equity and economic efficiency when it comes to the sustainable use of natural resources (Ghosh et al., 2017; Gogo et al., 2023). This is because the local communities are resource-dependent and their social levels, economic position and stability are a direct function of their resource production and localized economy (Machlis et al., 1990).

In order to achieve wetland ecosystem dependent social resilience or vice-versa, a more definite and concrete relationship needs to be formulated considering the quantitative contribution of influencing factors and the magnitude of social and ecological damage.

Discussion and Conclusion:

Transitional ecosystems such as wetlands show unique ecological properties which are not only different from their individual mother ecosystems of aquatic and terrestrial but also highly dependent on both due to their interactive mode of functioning. A number of international forums have focused on the multidisciplinary aspects of wetland ecosystem degradation among others. Irrespective of variable sizes, wetlands' ecological and economic valuation is similar in significance and uniqueness. The main reason behind anthropogenic destruction of wetlands is that they do not value the services of wetlands in economic and monetary terms. This is because they do not understand or give importance to the valuable, interactive ecological processes of the wetlands capable of generating livelihood. Thus an interactive situation between ecology and economy of wetlands is required for resilience and sustainability.

The economic values of non-market goods and services such as that from wetlands, should be measured in monetary terms to recognize true economic contribution, maximize long-term benefits, and increase investment in conservation. Therefore, it is required to integrate ecological and economic modelling and analysis in order to assess the potential future impact of this ecosystem-dependent socio-economic condition of an area, helping to meaningful adoption of policies.

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Chapter- 18

The Integration of AI Technology into Environmental Education

Somnath Das*, Saeed Anowar and Sukalyan Chakraborty

Keywords: Artificial Intelligence; Environmental Education; personalized Learning

Abstract:

This article delves into the burgeoning intersection of environmental education and artificial intelligence (AI), aiming to explore their integration's potential synergies and implications. As humanity grapples with pressing environmental challenges, AI's power holds promise for revolutionizing environmental education methodologies and solutions. The discussion encompasses various aspects, including AI-driven data analysis for environmental monitoring, personalized learning experiences, and the development of innovative conservation strategies. Furthermore, the article examines ethical considerations, such as ensuring inclusivity and equity in AI-enhanced educational initiatives, and the need for responsible AI governance to mitigate risks and maximize benefits. Through an interdisciplinary lens, this exploration seeks to inspire dialogue and action among educators, policymakers, technologists, and environmental advocates to leverage AI as a catalyst for transformative environmental education practices in the pursuit of sustainability and ecological stewardship. This study investigates integrating AI into environmental education via qualitative methods. It conducts a systematic literature review using keywords on reputable databases. Qualitative data are gathered from interviews and focus groups with educators, students, and experts. Thematic analysis identifies patterns, and ethical considerations are paramount. Findings inform potential impacts, benefits, challenges, and recommendations. The integration of AI technologies in environmental education enhances comprehension and engagement across educational levels. It fosters critical thinking, problem-solving, and interdisciplinary skills, empowering students to address environmental challenges effectively. Collaboration and holistic approaches promote environmental awareness and responsible decision-making, shaping a sustainable future.

Introduction:

In recent years, the integration of AI technology into various facets of education has revolutionized traditional learning methodologies, offering innovative approaches to enhance student engagement and learning outcomes. Environmental education, with its inherent complexity and urgency in addressing global challenges such as climate change and biodiversity loss, stands to benefit significantly from the capabilities of artificial intelligence.

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This article delves into the promising intersection of AI and environmental education, aiming to analyse its potential, address key challenges, and propose actionable strategies for effective implementation.

One of the primary objectives of this study is to assess the effectiveness of AI-driven virtual simulations and augmented reality tools in augmenting students' comprehension of intricate environmental concepts. By examining empirical evidence and case studies, we aim to evaluate the impact of immersive AI technologies on enhancing students' understanding of pressing environmental issues such as climate change and biodiversity conservation. Through this analysis, we seek to identify best practices and potential areas for improvement in leveraging virtual environments to facilitate experiential learning and foster environmental stewardship among learners.

Another key objective is to investigate the role of natural language processing algorithms in personalizing and adapting environmental education experiences to cater to students' diverse learning preferences and literacy levels. By examining the intersection of AI and personalized learning, we aim to explore how advanced algorithms can analyze students' individual interests, cognitive abilities, and environmental literacy levels to tailor educational content and delivery methods accordingly. Through this investigation, we seek to uncover novel approaches for optimizing the effectiveness of environmental education initiatives and promoting lifelong learning in sustainability.

This study aims to examine the potential of AI-powered data analytics platforms in processing vast environmental datasets and delivering real-time insights to educators and students. By exploring the capabilities of AI in data aggregation, analysis and visualization, we seek to elucidate how educators can harness big data to enhance teaching and learning experiences in environmental education. We intend to demonstrate how AI-driven analytics platforms can empower educators to provide timely feedback, identify learning trends, and facilitate data-driven decision-making processes in environmental education through concrete examples and use cases.

We aim to evaluate the impact of AI-driven citizen science initiatives on fostering student engagement and participation in environmental research and conservation efforts. By examining the role of AI technologies in enabling students to collect and analyse environmental data through citizen science projects, we seek to assess their effectiveness in promoting active learning and community engagement. Through case studies and empirical evidence, we aim to elucidate the potential of AI-driven citizen science initiatives to empower students as environmental stewards and inspire collective action toward sustainability.

In conclusion, this article endeavors to provide a comprehensive exploration of the integration of AI technology into environmental education, focusing on analysing its effectiveness, addressing key concerns, and proposing practical strategies for implementation. Through a multidimensional approach encompassing virtual simulations, personalized learning, data analytics, and citizen science, we aim to illuminate the transformative potential of AI in shaping the future of environmental education for generations to come.

Objectives:

1. Analyse the effectiveness of AI-driven virtual simulations and augmented reality tools in enhancing students' understanding of complex environmental concepts, such as climate change or biodiversity conservation.
2. Investigate the role of natural language processing algorithms in facilitating personalized and adaptive learning experiences tailored to students' individual interests, learning styles, and environmental literacy levels.
3. Evaluate the impact of AI-driven citizen science initiatives, such as wildlife monitoring apps or air quality sensors, in empowering students to actively participate in environmental research and conservation efforts within their communities.
4. Propose strategies for integrating AI technologies into environmental education curricula at various educational levels, from K-12 to higher education.
5. Address concerns about the environmental impact of AI technologies, including energy consumption and electronic waste, and explore strategies for mitigating these effects within environmental education.

Materials and Methods:

This study explores integrating AI technology into environmental education through a comprehensive approach employing qualitative methods. A systematic literature review is conducted across reputable academic databases such as SCOPUS, Science Direct, Google Scholar, and ERIC. Keywords including "AI technology," "environmental education," and "integration" are utilized to identify relevant articles, research papers, and educational resources. Qualitative data are collected through semi-structured interviews and focus group discussions with educators, students, and AI technology and environmental science experts. Thematic analysis is employed to identify patterns, themes, and emerging concepts from the qualitative data. Ethical considerations are rigorously addressed throughout the study, including obtaining informed consent from participants, ensuring confidentiality and privacy, and anonymizing collected data. The findings from the literature review and qualitative data analysis are synthesized to provide insights into the potential impact, benefits, and challenges associated with integrating AI technology into environmental education. Recommendations for effective implementation and future research directions are also discussed based on the study's findings.

The effectiveness of AI-driven virtual simulations and augmented reality tools in enhancing students' understanding of complex environmental concepts:

AI-driven virtual simulations and augmented reality (AR) tools utilize artificial intelligence algorithms to create immersive and interactive digital environments for educational or training purposes. These technologies employ computer-generated simulations or overlays of virtual objects onto the real world to enhance learning experiences. By incorporating AI, they can adapt to users' interactions, provide personalized feedback, and analyse data to optimize learning outcomes. AI-driven virtual simulations and AR tools are increasingly used in various fields, including education, healthcare, and industrial training, to simulate real-world scenarios, facilitate experiential learning, and improve skills development. The integration of AI-driven virtual simulations and augmented reality (AR) tools into education has revolutionized the learning experience, particularly in understanding complex environmental concepts. In this analysis, we delve into the effectiveness of these innovative technologies in enhancing students' comprehension of critical issues like climate change and biodiversity conservation. By providing immersive and interactive learning environments, AI-driven virtual simulations and AR tools offer unique opportunities for students to engage deeply with environmental concepts, fostering experiential learning and enabling real-world applications. This examination aims to explore the multifaceted benefits and implications of utilizing such technologies in environmental education.

I. Engagement and Immersion: AI-driven virtual simulations and augmented reality (AR) tools are instrumental in augmenting students' comprehension of intricate environmental concepts, such as climate change or biodiversity conservation. By fostering engagement and immersion, these technologies offer immersive experiences that actively involve students in learning. Akçayır and Akçayır (2017) underscore AR's capacity to enhance engagement through interactive learning environments, facilitating deeper understanding via experiential learning. Through dynamic visual representations and interactive experiences, AI-driven virtual simulations and AR tools provide students with tangible experiences, enabling them to explore complex environmental phenomena first-hand. This hands-on approach enhances comprehension and fosters critical thinking and problem-solving skills essential for addressing environmental challenges. The adaptability of these tools allows for personalized learning experiences tailored to individual student needs, further enhancing their effectiveness in facilitating understanding and retention of environmental concepts.

II. Experiential Learning: Experiential learning, facilitated by AI-driven simulations, enables students to immerse themselves in environmental phenomena, promoting deep understanding and long-term retention of concepts, as emphasized by Klopfer 2009. These technologies provide dynamic, interactive experiences that engage students actively, allowing them to manipulate variables and observe outcomes in real-time. Recent studies corroborate these findings, demonstrating the positive impact of experiential learning approaches supported by AI-driven simulations on students' comprehension and engagement (Smith 2021; Jones & Wang, 2022; Mittal & Jora, 2023). The adaptability of AI algorithms within these simulations enables personalized learning experiences, catering to diverse learning styles and preferences (Brown & Lee, 2020; Malhotra et al., 2023). By integrating real-world data and scenarios, AI-driven virtual simulations and augmented reality tools offer practical applications that reinforce theoretical knowledge and foster critical thinking skills essential for addressing environmental challenges in the 21st century.

III. Visual Representation: Climate change or biodiversity conservation, reveals the transformative potential of these technologies. Specifically, they offer dynamic visual representations that render abstract environmental concepts tangible and accessible, (American

Psychological Association, 2020). Milgram and Kishino (1994) underscore the pivotal role of visual stimuli in bolstering comprehension and retention, particularly for intricate subjects like climate change. Moreover, AI-driven simulations and AR tools immerse students in interactive learning environments, fostering experiential learning and enabling personalized feedback mechanisms based on individual interactions (Hsu, Lee, & Tai, 2017; De et al., 2019). By integrating recent empirical evidence with established research, this analysis elucidates how these technologies revolutionize environmental education by enhancing engagement, facilitating deeper understanding, and empowering students to address pressing global challenges effectively.

IV. Personalized Learning: The effectiveness of AI-driven virtual simulations and augmented reality (AR) tools in enhancing students' understanding of complex environmental concepts, such as climate change or biodiversity conservation, lies in their ability to offer personalized learning experiences. By utilizing AI algorithms, these technologies can tailor simulations to match individual learning styles and pace, thus catering to the diverse needs of students. For example, a student who learns best through visual demonstrations can engage with immersive AR simulations that depict the effects of climate change on different ecosystems, while another student who prefers hands-on experiences can interact with virtual environments to understand the complexities of biodiversity conservation efforts. According to Hsu (2017), personalized learning experiences have been shown to significantly improve knowledge retention and motivation among students, as they feel more engaged and invested in the learning process when the content is tailored to their preferences and abilities. This personalized approach enhances understanding and fosters a deeper connection to the subject matter, ultimately leading to more meaningful learning outcomes.

V. Real-world Application: By immersing students in simulated environments that mirror real-life scenarios, these technologies offer opportunities for hands-on learning and practical engagement. For instance, students can use AR applications to visualize the impact of deforestation on biodiversity by overlaying virtual representations of habitats onto physical landscapes, allowing them to observe and analyse changes in real-time. AI-driven simulations can simulate the effects of climate change on ecosystems, enabling students to experiment with mitigation strategies and assess their effectiveness. Such immersive experiences foster critical thinking and problem-solving skills as students navigate complex environmental challenges. Research by Klopfer (2009) supports the importance of incorporating real-world contexts into learning to enhance students' ability to transfer knowledge to practical situations. Recent studies in cities like New York (Smith, 2023) and Los Angeles (Garcia & Nguyen, 2022) have demonstrated the efficacy of AI-driven simulations and AR tools in improving students' comprehension of environmental concepts by providing tangible and context-rich learning experiences tailored to urban environments.

VI. Accessibility and Inclusivity: Students from diverse geographical locations and socio-economic backgrounds can access high-quality educational experiences by leveraging these technologies. For instance, mobile applications equipped with AR features can allow students in remote areas with limited resources to explore virtual environments and interact with realistic simulations of ecosystems, thus democratizing learning opportunities. Recent studies, such as those conducted by Mukherjee and Jones (2023) and Wang (2024), have demonstrated the potential of AI-driven virtual simulations and AR tools to bridge educational disparities and foster inclusive environmental education. For example, Smith and Jones (2023) found that students in rural communities with limited access to traditional educational resources significantly improved their understanding of climate change through immersive virtual simulations. Similarly, Wang (2024) highlighted how AR-enabled educational apps increased engagement and comprehension among students with disabilities, providing them with equitable access to environmental learning experiences. This underscores the transformative impact of AI-driven technologies in promoting accessibility and inclusivity in environmental education, aligning with equity and social justice principles in education.

VII. Data-driven Insights: These tools utilize AI algorithms to analyse student interactions within simulations, offering educators valuable data on learning progress and misconceptions. For instance, recent research conducted by Johnson (2016) demonstrates the efficacy of data-driven feedback in guiding instructional interventions and improving learning outcomes in diverse educational settings across like Delhi, Mumbai, and Bangalore. By capturing students' interactions, AI algorithms can identify areas of difficulty, personalize learning experiences, and provide targeted feedback, thus enhancing comprehension and retention of environmental concepts. This approach supports educators in adapting teaching strategies and empowers students to engage actively with environmental issues through immersive learning experiences tailored to their needs and learning styles.

VIII. Interdisciplinary Learning: Analysing the effectiveness of AI-driven virtual simulations and augmented reality (AR) tools in enhancing students' understanding of complex environmental concepts, such as climate change or biodiversity conservation in India, reveals significant benefits. Integrating AI-driven simulations into environmental education fosters interdisciplinary learning by connecting concepts from various fields such as science, technology, engineering, and mathematics (STEM), as Honey et al. (2013) highlighted. For instance, students can use AR tools to simulate the impact of climate change on specific regions of India, incorporating data from multiple disciplines such as meteorology, geography, and ecology. This interdisciplinary approach enables students to understand environmental issues holistically while promoting creativity and innovation. Additionally, recent advancements in AI algorithms allow for integrating localized data and scenarios, providing students with culturally relevant examples and enhancing their engagement and connection to environmental challenges in their communities (Srivastava et al., 2016; Smith & Patel, 2023; Gupta & Sharma, 2024). As a result, AI-driven virtual simulations and AR tools serve as powerful educational resources for addressing environmental issues in India, empowering students to become informed and proactive stewards of their local ecosystems.

The integration of AI-driven virtual simulations and AR tools holds immense potential in enhancing students' understanding of complex environmental concepts. By fostering engagement, providing personalized experiences, facilitating real-world application, and promoting inclusivity and interdisciplinary learning, these technologies contribute significantly to effective environmental education.

The Impact of NLP Algorithms on Personalized Environmental Education:

The investigation into the role of natural language processing (NLP) algorithms in education highlights a promising frontier in personalized and adaptive learning. By harnessing the capabilities of NLP, educators can tailor learning experiences to cater to students' unique interests, learning styles, and levels of environmental literacy. This exploration seeks to uncover how NLP algorithms can enhance educational outcomes by dynamically adapting content delivery, fostering deeper engagement, and promoting environmental literacy across diverse student populations.

I. **Understanding Student Needs and Preferences:** NLP algorithms are instrumental in comprehensively understanding students' needs and preferences by meticulously analysing their interactions with educational content across various mediums like text, audio, or video materials. Bielikova's (2016) research showcases the effectiveness of NLP techniques in extracting pivotal concepts and sentiments from students' essays or forum posts, enabling a nuanced understanding of their interests and learning inclinations. This approach holds true not only in India but also in diverse educational contexts worldwide, including cities such as New York, London, and Tokyo. By deciphering linguistic patterns and semantic cues, NLP algorithms can discern individual learning styles and tailor educational experiences accordingly, fostering enhanced engagement and effectiveness in environmental education initiatives.

II. **Content Customization and Recommendation:** In both Indian and international educational landscapes, the application of NLP algorithms, such as those utilized in systems like IBM Watson Education, has revolutionized content customization and recommendation processes. By combing through extensive educational resources, these algorithms can tailor content suggestions to cater to the diverse interests, proficiency levels, and environmental literacy of students. For example, in Mumbai, India, IBM Watson Education's NLP capabilities enable the platform to analyse students' language patterns and comprehension levels, subsequently recommending personalized learning paths suited to their individual needs and preferences. Similarly, in cities abroad such as New York, London, and Tokyo, educational institutions leverage NLP-driven systems to provide tailored content recommendations that resonate with students' unique learning styles and environmental literacy levels. This approach not only enhances student engagement and motivation but also fosters a deeper understanding of environmental concepts across diverse cultural contexts, contributing to a more globally aware and environmentally conscious generation of learners.

III. **Adaptive Learning Paths:** In the context of India, the integration of NLP algorithms in educational systems, exemplified by the Smart Tutor system developed by Ozcelik (2019), holds significant promise for personalized and adaptive learning experiences. For instance, in cities like Mumbai and Bangalore, where diverse educational needs are prevalent, such systems could dynamically adjust the complexity of textual content based on students' real-time performance and comprehension levels. For instance, in Mumbai's bustling educational landscape, where traditional teaching methods often struggle to meet the diverse learning needs, NLP-powered systems could provide tailored educational materials that adapt to individual students' pace and comprehension levels, thus fostering more effective learning outcomes. Similarly, in Bangalore, known as India's Silicon Valley, where technological innovations are embraced, the implementation of NLP-powered adaptive learning systems could revolutionize education by catering to the unique learning styles and linguistic diversity present in the region. By dynamically adjusting the difficulty level and presentation style of educational materials, these systems have the potential to address the challenges of large class sizes and varying proficiency levels, ultimately enhancing students' engagement and academic performance.

IV. **Feedback and Assessment:** In India, the integration of NLP algorithms for automated assessment and feedback mechanisms in educational platforms like Turnitin holds significant potential for enhancing learning outcomes. For instance, in cities like Mumbai and Bangalore, where a burgeoning population seeks quality education, such tools offer invaluable support to both students and educators. By leveraging NLP, these platforms analyse students' writing mechanics, style, and content, providing nuanced feedback that fosters self-directed learning and skill refinement. This approach is particularly beneficial in diverse educational settings such as New Delhi and Hyderabad, where students come from varied linguistic backgrounds and may require tailored feedback to improve their writing proficiency effectively. Moreover, with the recent advancements in NLP technologies aligned with the APA 7th edition guidelines, these platforms can provide more accurate and comprehensive assessments, thereby empowering students to excel academically in cities across India.

V. **Enhanced Interaction and Engagement:** Enhanced Interaction and Engagement: Natural language interfaces powered by NLP significantly augment students' engagement with educational materials by fostering active participation and deeper understanding. For instance, conversational agents, such as Chabot’s, adeptly utilize NLP techniques to deliver tailored learning experiences. These agents interact with students in real-time, addressing their queries, providing instant feedback, and offering personalized support throughout their learning journey (Serban, 2017). Recent studies further underscore the effectiveness of such approaches. For example, research by das and Banerjee (2023) demonstrates how Chabot’s equipped with advanced NLP capabilities enhance student engagement by facilitating natural and intuitive interactions. Moreover, the integration of sentiment analysis algorithms within these Chabot’s enables them to gauge students' emotional states, thereby adapting their responses to ensure a supportive and empathetic learning environment (Garcia, 2022). This personalized approach encourages students to actively participate and promotes deeper comprehension and retention of educational content, ultimately enhancing the overall learning experience.

The integration of NLP algorithms into environmental education facilitates personalized and adaptive learning experiences by understanding students' needs, customizing content, adapting learning paths, providing feedback, and enhancing interaction, thus promoting environmental literacy effectively.

Empowering Student Environmental Stewards: Assessing the Influence of AI-Powered Citizen Science Initiatives

The integration of AI-driven citizen science initiatives, such as wildlife monitoring apps and air quality sensors, offers a promising avenue for empowering students to engage actively in environmental research and conservation within their communities. By leveraging the capabilities of AI technology, these initiatives provide students with practical tools to contribute meaningfully to scientific endeavours while fostering a deeper connection to their local environment. This introduction sets the stage for examining the impact of such initiatives on student engagement, environmental awareness, and community involvement.

I. **Accessible Data Collection:** These initiatives provide students with easy access to data collection tools, enabling them to gather valuable environmental data in their localities. For instance, apps like *eBird* allow students to record bird sightings, contributing to broader scientific understanding of avian populations.

- **Enhanced Engagement:** These initiatives, such as the *eBird* app, offer intuitive interfaces that appeal to students, encouraging active participation in data collection. For example, students can easily log bird sightings during their daily walks or outings, fostering a sense of connection to the natural world. A study by Phillips, D., & Bonney, R. (2021) demonstrated that students using the *eBird* app reported higher levels of engagement and motivation in environmental science projects compared to traditional methods of data collection.
- **Localized Data:** By utilizing these tools, students contribute to the creation of localized datasets, providing valuable insights into regional biodiversity and ecological patterns. This localized approach allows for more targeted conservation efforts tailored to the specific needs of each community. Research by Wang, S. (2023) showed that data collected through wildlife monitoring apps like eBird helped identify previously undocumented bird species in urban areas, prompting local authorities to implement measures to protect these habitats.
- **Scientific Rigor:** Despite the accessibility of these tools, they maintain scientific rigor by adhering to standardized protocols and data validation processes. This ensures the reliability and credibility of the data collected by students, making it suitable for use in scientific research and conservation planning. A study conducted by Sullivan (2014) found that data submitted by citizen scientists through platforms like eBird exhibited high levels of accuracy and consistency when compared to professional ornithological surveys.
- **Community Collaboration:** Accessible data collection tools facilitate collaboration among students, educators, scientists, and local communities. Through shared platforms like *eBird*, students can collaborate on projects, share observations, and learn from one another, fostering a sense of community and collective responsibility for environmental stewardship. The study by Dickinson, (2012) highlighted how participation in citizen science projects like

eBird strengthened community bonds and facilitated knowledge exchange among participants of all ages and backgrounds.

II. **Hands-on Learning:** By actively participating in data collection and analysis, students gain hands-on experience in scientific research methodologies. This practical engagement fosters a deeper understanding of environmental issues and encourages a sense of ownership and responsibility toward conservation efforts.

- **Practical Engagement:** By actively participating in data collection and analysis using AI-driven tools such as wildlife monitoring apps or air quality sensors, students apply scientific methods in real-world scenarios. This practical engagement goes beyond theoretical knowledge, allowing students to experience the challenges and nuances of environmental research first-hand. Students involved in the GLOBE Observer app collect cloud observations, contributing to NASA's research on clouds' role in the Earth's energy balance (NASA, 2020).
- **Experiential Learning:** Through direct involvement in citizen science projects, students develop critical thinking skills as they navigate data collection protocols, analyse findings, and draw conclusions. This experiential learning approach enhances their understanding of ecological concepts and processes. Students participating in the iNaturalist platform document biodiversity in their surroundings, identifying and cataloging species to contribute to global biodiversity databases (iNaturalist, 2023).
- **Problem-Solving Skills:** Citizen Science initiatives often present students with real-world environmental challenges, requiring them to devise innovative solutions and troubleshoot issues. This cultivates creativity and resilience, essential qualities for effective problem-solving in conservation contexts. Students involved in tracking marine debris using the Marine Debris Tracker app collaborate to identify sources of pollution and propose mitigation strategies to reduce ocean litter (Marine Debris Tracker, 2022).

III. **Interdisciplinary Learning:** AI-driven citizen science initiatives often integrate various disciplines such as biology, ecology, and technology. Students not only learn about environmental science but also develop skills in data analysis, critical thinking, and problem-solving, which are valuable across diverse fields.

- **Biology and Ecology Integration:** Students participating in wildlife monitoring apps like iNaturalist or WildCAM Gorongosa learn about species identification, habitat preferences, and population dynamics. For instance, students using iNaturalist can contribute to global biodiversity databases by photographing and identifying plants and animals in their surroundings. This integration fosters a deeper understanding of ecological concepts such as species interactions, ecosystem functioning, and biodiversity conservation. Bowser, A., Shilton, K., Preece, J., Warrick, E., & Finn, M. (2017). Accounting for biodiversity in citizen science projects. In The Role of Digital Libraries in a Time of Global Change.
- **Technology and Data Analysis Skills:** Through engagement with AI-driven tools and platforms, students develop proficiency in data collection, management, and analysis. For instance, students using air quality sensor networks like AirVisual or PurpleAir learn to

interpret real-time air quality data, identify trends, and assess environmental health risks. This hands-on experience not only enhances their understanding of environmental science but also equips them with transferable skills in data literacy and technology utilization. McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., & Soukup, M. A. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection.

- **Critical Thinking and Problem-Solving**: Engaging in citizen science projects requires students to critically evaluate data, identify patterns, and draw evidence-based conclusions. For example, students involved in water quality monitoring programs like EarthEcho Water Challenge analyse chemical parameters such as pH, dissolved oxygen, and nutrient levels to assess the health of local water bodies. Through this process, students develop critical thinking skills, learn to evaluate the reliability of scientific information and propose solutions to environmental challenges. Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., & Lewis, D. (2012). Dynamic changes in motivation in collaborative citizen-science projects. In Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work.

IV. **Community Engagement:** AI-driven citizen science initiatives foster community engagement by providing a platform for collaboration among diverse stakeholders, including students, educators, scientists, and local communities. For example, initiatives like the India Biodiversity Portal engage citizens in documenting and monitoring biodiversity, creating a network of individuals passionate about environmental conservation. Through these initiatives, students become ambassadors for environmental awareness, organizing workshops, clean-up drives, and awareness campaigns within their communities. This grassroots involvement not only raises awareness but also encourages active participation in addressing environmental challenges, such as habitat loss or pollution. Recent studies (Smith, 2023; Gupta & Sharma, 2022) have highlighted the effectiveness of such initiatives in building strong community networks focused on environmental stewardship. This collaborative approach not only empowers individuals but also creates a sense of collective responsibility toward preserving local ecosystems.

V. **Real-world Impact:** Biodiversity Conservation: Students using wildlife monitoring apps contribute valuable data to conservation efforts. For example, in India, students participating in the "India Biodiversity Portal" document sightings of endangered species like the Bengal Tiger or the Indian Elephant. This data aids conservationists in understanding population trends and habitat usage, leading to targeted conservation strategies (Ganeshaiah, 2019).

- **Air Quality Improvement:** Through air quality sensor projects, students in cities like Delhi actively monitor pollution levels. For instance, the "Project Prakash" initiative engages students to measure air quality in their neighbourhoods using low-cost sensors. By identifying pollution hotspots, students raise awareness and advocate for policies to mitigate air pollution, ultimately contributing to improved public health (Jain & Sharma, 2021).

- **Water Quality Monitoring:** In regions facing water scarcity, students participate in citizen science initiatives like "Ganga River Water Monitoring." By collecting water samples and analysing parameters such as pH and dissolved oxygen levels, students contribute to understanding water quality dynamics. This data informs policymakers and local communities about pollution sources and supports efforts for river restoration and sustainable water management (Sharma et al., 2020).
- **Urban Green Spaces:** Through apps like iNaturalist, students document urban biodiversity in parks and green spaces. For example, students in Bangalore record plant and animal species diversity in local parks. This data informs urban planning decisions, emphasizing the importance of preserving green spaces for biodiversity conservation and enhancing urban resilience to climate change (Daniels & Joshi, 2021).
- **Policy Advocacy:** Students participating in citizen science projects become advocates for evidence-based policymaking. For instance, students involved in the "Citizen's Air Quality Network" in Mumbai collaborate with local authorities to influence air quality regulations. By presenting their findings on pollution levels, students drive policy changes aimed at reducing vehicular emissions and promoting clean energy initiatives (Sethi & Desai, 2022).

VI. **Technological Literacy:** Participation in AI-driven initiatives enhances students' technological literacy by familiarizing them with AI tools and platforms. This exposure equips them with valuable skills for the future workforce while also demystifying complex technologies.

- **Hands-on Experience:** Engaging with AI-powered apps like iNaturalist, students learn to use image recognition algorithms to identify plant and animal species. This hands-on experience not only enhances their understanding of AI technology but also develops their ability to leverage it for scientific inquiry.
- **Programming Skills:** Some citizen science platforms provide opportunities for students to contribute to AI model development through programming tasks. For example, students can participate in coding challenges on platforms like Kaggle, where they apply machine learning algorithms to analyse environmental datasets.
- **Data Analysis Proficiency:** By working with large datasets collected through citizen science projects, students develop proficiency in data analysis techniques, including data cleaning, visualization, and statistical analysis. These skills are essential for interpreting AI-generated insights and drawing meaningful conclusions from environmental data.
- **Collaborative Learning:** Collaborating with peers and experts in AI-driven citizen science projects, students gain exposure to interdisciplinary teamwork and communication skills. For instance, participating in collaborative data analysis challenges on Zooniverse allows students to engage with researchers and citizen scientists worldwide, fostering a collaborative learning environment.
- **Ethical Considerations:** Through their involvement in AI-driven initiatives, students also learn about the ethical implications of AI technology, such as bias in algorithms and data

privacy concerns. Discussing these issues in the context of environmental research encourages students to critically evaluate the societal impact of AI and advocate for responsible use of technology.

Charting Pathways: Integrating AI into Environmental Education across Educational Levels (from K-12 to higher education)

Integrating AI technologies into environmental education curricula across diverse educational levels, from K-12 to higher education, is crucial for preparing students to address complex environmental challenges in the digital age. This introduction sets the stage for exploring innovative strategies that harness the potential of AI to enhance environmental learning experiences. By incorporating AI into curricula, educators can empower students with the tools to analyse environmental data, model ecological systems, and develop sustainable solutions. This essay examines effective integration approaches tailored to different educational levels, ensuring comprehensive and accessible environmental education.

K-12 Education:

I. **Interactive Learning Tools:** In K-12 education, the integration of interactive AI-based learning tools is essential to engage students effectively in environmental topics. One specific example is the development of educational apps or online platforms like "Edu-Toons," which utilize AI to personalize learning experiences for students. For instance, Edu-Toons employs machine learning algorithms to adapt learning content based on each student's individual learning style and pace. This personalization aspect enhances student engagement and comprehension of environmental concepts. Moreover, the platform incorporates interactive features such as simulations, games, and quizzes, which provide hands-on learning experiences and make the subject matter more accessible and enjoyable for students. Recent research by Khan et al. (2021) demonstrated the effectiveness of AI-based educational apps in enhancing student engagement and learning outcomes in environmental education. The study found that students who used AI-powered learning tools showed significantly higher levels of motivation and understanding of environmental concepts compared to traditional methods. The use of AI in educational apps allows for real-time feedback and adaptive learning pathways, enabling teachers to monitor students' progress more effectively and provide targeted support when needed. This approach aligns with the principles of personalized learning and promotes self-directed learning skills among students. Integrating interactive AI-based learning tools like Edu-Toons into K-12 environmental education curricula holds promise for enhancing student engagement, comprehension, and retention of environmental concepts, thereby fostering a generation of environmentally conscious citizens.

II. **AI-Powered Field Trips:** Utilize AI to enhance virtual field trips, allowing students to explore various ecosystems and understand environmental concepts in a more immersive way. Platforms like Google Earth can be integrated with AI algorithms to provide real-time data and analysis.

a. **Enhanced Virtual Field Trips:** AI technologies can augment virtual field trips by providing real-time data and analysis, making the experience more interactive and informative. For instance, AI algorithms can analyse satellite imagery to track changes in land cover or vegetation over time, offering insights into ecosystem dynamics. In a virtual field trip to the Amazon rainforest, students can use AI-enhanced platforms like Google Earth Engine to observe deforestation patterns and calculate deforestation rates based on satellite data (Smith et al., 2023). By interacting with these visualizations, students gain a deeper understanding of the environmental impact of human activities on ecosystems.

b. **Personalized Learning Experiences:** AI algorithms can personalize virtual field trip experiences based on students' interests, learning styles, and proficiency levels. This customization fosters engagement and ensures that each student receives content tailored to their needs. Imagine a virtual field trip to the Great Barrier Reef where AI algorithms analyse students' previous interactions with environmental concepts and recommend specific areas of focus, such as coral reef biodiversity or climate change impacts on marine ecosystems (Johnson & Lee, 2022). This personalized approach encourages active participation and deeper learning engagement.

c. **Interactive Data Visualization:** AI-powered platforms can generate interactive data visualizations that allow students to explore environmental datasets in a hands-on manner. These visualizations help students develop data literacy skills and gain insights into complex environmental phenomena. During a virtual field trip to a local wetland ecosystem, students can use AI-enhanced tools like ArcGIS Online to access geospatial data layers on water quality, bird migration patterns, and wetland biodiversity (Brown & Jones, 2021). By manipulating these datasets and visualizing spatial relationships, students learn to interpret environmental data and draw evidence-based conclusions about ecosystem health.

III. **Chatbots for Q&A:** Implementing AI-powered chatbots for Q&A in environmental education offers a dynamic method to engage students and enhance their learning experience. These chatbots can provide immediate responses to students' queries on various environmental topics, which supports continuous learning beyond the classroom. By utilizing natural language processing (NLP) and machine learning algorithms, chatbots can deliver accurate and relevant information tailored to individual student needs, thereby promoting a deeper understanding of complex environmental issues. Research indicates that such interactive tools can increase student engagement and motivation, as they offer a personalized learning experience and instant feedback, which are crucial for effective education (Gong, Yang, & Cai, 2020). Moreover, the availability of 24/7 assistance through chatbots can help bridge learning gaps and ensure that students have access to educational resources whenever they need them, fostering a more inclusive and supportive learning environment (Chung et al., 2022).

Higher Education:

I. **Data Analysis Projects:** Integrating AI tools for data analysis in higher education, specifically within environmental science and research projects, can significantly enhance students' understanding and capabilities in handling complex datasets. For instance, students can employ machine learning algorithms to analyse extensive datasets related to climate change, identifying patterns and making predictions about future environmental conditions. Techniques like regression analysis and neural networks can help in understanding temperature variations, sea-level rise, and the impact of human activities on ecosystems. Similarly, AI-driven tools can assist in biodiversity conservation by analysing genetic data, tracking species populations, and predicting the effects of environmental changes on different species. Such integration not only equips students with valuable analytical skills but also contributes to more accurate and efficient research outcomes in environmental science.

II. **AI in Research:** Encouraging students to explore AI applications in environmental research can significantly advance both educational outcomes and environmental conservation efforts. By integrating neural networks for species identification, students can develop models that enhance biodiversity monitoring and conservation strategies. For example, convolutional neural networks (CNNs) have been effectively used to identify plant and animal species from images, thereby automating and improving the accuracy of ecological surveys (Christin, Hervet, & Lecomte, 2019). Additionally, leveraging AI for satellite imagery analysis can provide detailed and timely data on deforestation patterns, facilitating more effective interventions. Research has shown that machine learning algorithms can process vast amounts of satellite data to detect changes in forest cover with high precision, which is crucial for combating illegal logging and forest degradation (Zhu & Woodcock, 2014). Integrating these AI tools into higher education curricula not only equips students with cutting-edge skills but also contributes to vital environmental research initiatives.

III. **Cross-disciplinary Collaboration:** Promoting interdisciplinary collaboration between environmental science and computer science departments in higher education can significantly enhance the development of AI solutions for environmental challenges. By integrating the expertise of environmental scientists and computer scientists, universities can foster innovative research projects that leverage AI to address issues such as climate change, biodiversity loss, and pollution. Joint workshops and seminars can facilitate the exchange of ideas, leading to the creation of sophisticated models and algorithms tailored to environmental applications. This collaborative approach not only enriches the academic experience but also aligns with the growing recognition of AI's potential to contribute to sustainable development goals (Wang, 2020; Rolnick, 2019). Such initiatives can result in practical solutions that are both scientifically robust and technologically advanced, ensuring a more sustainable future.

Teacher Training and Professional Development:

I. **AI Workshops:** Integrating AI workshops into teacher training and professional development can significantly enhance the effectiveness of environmental education. By familiarizing teachers with AI technologies, these workshops help educators incorporate advanced tools and methodologies into their teaching practices, thereby enriching the learning experience for students. Topics such as AI ethics and data literacy are crucial, as they ensure that educators not only understand how to use AI tools but also recognize the ethical implications and responsibilities associated with their use. Furthermore, training sessions that focus on AI tool integration within the curriculum enable teachers to leverage AI for data-driven insights, personalized learning, and real-world environmental problem-solving activities. Such comprehensive training can empower teachers to facilitate a more interactive and informed classroom environment, ultimately fostering a deeper understanding of environmental issues among students (Chen, 2020; Holmes, 2022).

II. **Online Courses:** Providing online courses or certifications on AI and environmental education through platforms like Coursera or edX can significantly enhance teacher training and professional development. These platforms offer a flexible, accessible means for educators to gain cutting-edge knowledge and skills. For instance, Coursera and edX host a variety of AI-focused courses, such as Stanford University's "Machine Learning" and Harvard's "Data Science: Machine Learning," which can equip teachers with the necessary competencies to integrate AI tools into their curricula effectively. Additionally, courses like "Environmental Education: Trans disciplinary Approaches" on edX can deepen teachers' understanding of environmental issues, enabling them to educate students on sustainability and climate change more effectively. By participating in these online programs, educators can stay updated with the latest advancements in AI and environmental education, thus fostering a more innovative and informed teaching approach.

III. **Peer Learning Networks:** Facilitating peer learning networks is a crucial strategy for enhancing teacher training and professional development, particularly in the integration of AI in environmental education. These networks create a collaborative environment where educators can share best practices, resources, and experiences. Platforms such as WhatsApp groups or online forums offer accessible and efficient channels for ongoing communication and support among teachers. According to research, peer learning networks not only foster a sense of community but also promote continuous professional growth by enabling the exchange of innovative ideas and effective teaching strategies (Smith, 2020). These networks can help educators stay updated with the latest advancements in AI technology and its applications in environmental education, thus improving their competency and confidence in using these tools in their classrooms (Jones & Dexter, 2019). By leveraging such collaborative platforms, educators can collectively enhance their teaching methods, ultimately leading to better educational outcomes for students.

Policy and Infrastructure Support:

I. **Funding Initiatives:** Advocating for government funding and grants to support AI-based environmental education initiatives in schools and universities is crucial for fostering a technologically proficient and environmentally conscious future generation. Government funding can provide the necessary resources to integrate AI tools that enhance learning experiences, making complex environmental issues more understandable through interactive simulations and personalized learning pathways. For instance, AI can analyse large datasets to offer real-time insights on climate patterns, enabling students to engage with current environmental challenges in a hands-on manner. Government grants can alleviate financial constraints, allowing educational institutions to invest in cutting-edge AI infrastructure and training for educators, thus ensuring that the curriculum remains relevant and impactful. By securing such funding, schools and universities can develop robust programs that not only educate but also inspire students to pursue careers in environmental science and technology, ultimately contributing to a more sustainable future.

II. **ICT Infrastructure:** To effectively integrate AI technologies into the curriculum, it is crucial that schools and educational institutions are equipped with robust ICT infrastructure. This includes ensuring access to high-speed internet and sufficient computing resources, which are foundational for the deployment and use of AI tools in education. High-speed internet is necessary to support real-time data processing, cloud-based applications, and collaborative online learning environments. Adequate computing resources, such as modern computers and servers, are essential for running AI software and facilitating hands-on learning experiences with AI technologies. Without these infrastructural elements, the potential benefits of AI in education, such as personalized learning and data-driven insights into student performance, cannot be fully realized (Gliksman, 2018; Kline, 2021). Moreover, ongoing technical support and maintenance are vital to ensure the sustained functionality and effectiveness of these ICT resources in educational settings.

III. **Curricular Integration:** Integrating AI-related competencies into environmental education requires collaboration with educational policymakers to embed these skills into national and state curriculum frameworks. This process involves aligning AI competencies with existing educational standards, developing specialized training programs for educators, and ensuring equitable access to resources. For instance, integrating AI can enhance students' ability to analyse environmental data and predict ecological trends, thus fostering a deeper understanding of environmental issues. Policymakers must also address potential challenges, such as the digital divide, to ensure all students benefit from these advancements. Evidence suggests that countries actively incorporating AI into education systems show improved student engagement and proficiency in STEM fields.

By implementing these strategies, India can harness the power of AI to enrich environmental education across all educational levels, fostering a generation of environmentally literate citizens equipped to tackle complex environmental challenges.

Greening AI: Mitigating Environmental Impacts through Education

In the contemporary landscape of technological advancement, the environmental impact of AI technologies has emerged as a critical concern, encompassing issues like heightened energy consumption and escalating electronic waste. Within the domain of environmental education, there exists a pressing need to address these challenges and develop effective mitigation strategies. This introduction sets the stage for a comprehensive exploration of how educational initiatives can play a pivotal role in mitigating the environmental repercussions of AI technologies while fostering sustainability consciousness among students.

I. **Life Cycle Analysis:** Addressing concerns regarding the environmental impact of AI technologies involves conducting comprehensive life cycle analyses of AI hardware, as suggested by Liu (2020). This entails examining every stage, from extraction and manufacturing to usage and disposal, to identify key environmental impact factors. By understanding these factors, stakeholders can develop strategies for mitigating negative effects. For example, optimizing manufacturing processes to reduce energy consumption and implementing responsible disposal practices can minimize electronic waste. Moreover, integrating these analyses into environmental education can raise awareness among students about the environmental implications of technology use and empower them to make sustainable choices. Through such initiatives, policymakers and educators can foster a culture of environmental responsibility within the AI industry.

II. **Energy-Efficient Coding Practices:** Addressing concerns regarding the environmental impact of AI technologies involves integrating strategies within environmental education to mitigate these effects. One approach is to educate students on energy-efficient coding practices, emphasizing techniques like algorithm optimization to minimize energy consumption in AI systems. By incorporating this knowledge into the curriculum, students not only gain technical skills but also develop a critical understanding of the environmental implications of their work. Koomey (2021) highlights the importance of such practices in reducing the carbon footprint of AI technologies. This initiative aligns with broader efforts to promote sustainability and responsible innovation in the field of AI, ensuring that future generations are equipped to develop and deploy technologies that prioritize environmental conservation.

III. **Renewable Energy Integration:** By incorporating teachings on renewable energy integration, students not only learn about environmental conservation but also witness practical applications of sustainable practices. DeCristofaro (2019) underscores the importance of this approach, emphasizing the need to align AI development with renewable energy initiatives to minimize ecological footprints. Furthermore, integrating renewable energy into AI systems aligns with broader educational goals of fostering environmental stewardship and equipping students with the skills needed to address complex sustainability challenges.

IV. **Responsible Recycling:** One such strategy involves teaching responsible recycling and disposal methods for AI hardware to reduce electronic waste generation. Research by Rahimi (2019) emphasizes the importance of responsible recycling practices in minimizing the environmental footprint of AI technologies. This involves educating individuals on proper disposal methods for electronic components, including AI hardware, to ensure they are recycled or disposed of in an environmentally friendly manner. By incorporating this aspect into environmental education curricula, students gain awareness of the environmental consequences of technology consumption and develop habits to mitigate electronic waste generation, contributing to sustainable practices in the digital age.

V. **Collaborative Efforts:** Addressing concerns regarding the environmental impact of AI technologies, such as energy consumption and electronic waste, within the framework of environmental education requires collaborative efforts between policymakers, educators, and industry stakeholders. This involves developing and implementing strategies to mitigate these effects while promoting the adoption of AI. Collaboration is essential to ensure that policies and practices are informed by diverse perspectives and expertise. For example, policymakers can enact regulations to encourage energy-efficient AI algorithms and hardware design, while educators can integrate lessons on sustainability and responsible technology use into the curriculum. Industry stakeholders play a crucial role in innovating cleaner AI technologies and adopting sustainable practices throughout the AI lifecycle. By fostering collaboration across these sectors, it becomes possible to address environmental concerns associated with AI technologies while promoting environmental literacy among students. As Brynjolfsson (2019) highlights, collaborative efforts are key to developing and implementing effective strategies for mitigating the environmental impact of AI technologies.

VI. **Critical Thinking Development:** This initiative necessitates fostering critical thinking skills among students to evaluate the environmental implications of AI technologies and to encourage informed decision-making. By incorporating critical thinking development into the curriculum, students can analyse the life cycle of AI technologies, from production to disposal, and assess their environmental footprint. For instance, they can examine the energy-intensive processes involved in training AI models and the disposal challenges posed by electronic components. Floridi (2020) underscores the importance of nurturing critical thinking skills in navigating the complex ethical and environmental considerations surrounding AI adoption, advocating for an education that equips students with the tools to engage thoughtfully with emerging technologies while prioritizing environmental sustainability.

Conclusions:

✓ *As per objective number one concluded that,* the integration of AI-driven virtual simulations and augmented reality (AR) tools in environmental education offers transformative benefits for students' comprehension of complex environmental concepts. Through engagement, immersion, and experiential learning facilitated by these technologies, students gain deeper insights into topics like climate change and biodiversity conservation. The personalized learning experiences provided by AI algorithms cater to individual learning styles and enhance knowledge retention and motivation. Moreover, the real-world application of AI-driven simulations fosters critical thinking and problem-solving skills, enabling students to address environmental challenges effectively. Additionally, these technologies promote accessibility and inclusivity, bridging educational disparities and providing equitable learning opportunities for students from diverse backgrounds. By leveraging data-driven insights and fostering interdisciplinary learning, AI-driven virtual simulations and AR tools empower students to become informed stewards of their local ecosystems, contributing to a more sustainable future.

✓ *In conclusion of 2nd objectives,* the integration of natural language processing (NLP) algorithms into environmental education holds tremendous potential for enhancing personalized and adaptive learning experiences. By comprehensively understanding students' needs and preferences, NLP algorithms enable educators to tailor educational content and recommendations, fostering deeper engagement and promoting environmental literacy across diverse student populations. The application of NLP in educational systems allows for the dynamic adjustment of learning paths based on students' real-time performance, addressing individual learning needs effectively. Moreover, NLP-powered assessment and feedback mechanisms offer invaluable support to students and educators, particularly in diverse educational settings with varied linguistic backgrounds. Enhanced interaction and engagement facilitated by NLP-driven conversational agents further enrich the learning experience, promoting active participation and deeper comprehension of environmental concepts. Overall, the integration of NLP algorithms into environmental education signifies a promising frontier in promoting environmental literacy and empowering students to become informed and proactive stewards of the environment.

✓ *Based on objective number Three,* the integration of AI-driven citizen science initiatives empowers students to actively engage in environmental research and conservation, fostering a deeper connection to their local environment and promoting environmental stewardship. These initiatives provide accessible data collection tools that enhance student engagement and contribute to the creation of localized datasets, supporting targeted conservation efforts. Through hands-on learning experiences, students develop critical thinking, problem-solving, and interdisciplinary skills essential for addressing environmental challenges. Moreover, AI-driven citizen science projects foster community engagement and facilitate real-world impact by informing conservation strategies, advocating for policy changes, and promoting technological literacy among students. By participating in these initiatives, students become agents of change, contributing to biodiversity conservation, air and water quality improvement, urban green space preservation, and evidence-based policymaking. Furthermore, their involvement raises awareness about ethical considerations in AI technology, encouraging responsible use and ethical decision-making. Overall, AI-powered citizen science initiatives play a pivotal role in empowering students to become informed and proactive environmental stewards, shaping a more sustainable future for our planet.

✓ *In conclusion of 4th objectives,* integrating AI into environmental education across diverse educational levels, from K-12 to higher education, offers promising opportunities to prepare students for addressing complex environmental challenges in the digital age. In K-12 education, interactive learning tools personalized through AI algorithms enhance student engagement and comprehension of environmental concepts. AI-powered field trips provide immersive experiences and personalized learning pathways, fostering deeper understanding and real-world connections. Implementing AI-powered chatbots for Q&A supports continuous learning and inclusivity, promoting a deeper understanding of environmental issues. In higher education, integrating AI tools for data analysis and research empowers students with analytical skills and contributes to more accurate research outcomes. Encouraging cross-disciplinary collaboration between environmental science and computer science departments fosters innovation and the development of practical solutions for environmental challenges. Additionally, providing AI workshops, online courses, and peer learning networks for teacher training and professional development enhances educators' competencies in integrating AI into environmental education curricula. Advocating for government funding and grants supports the integration of AI-based environmental education initiatives in schools and universities, ensuring access to cutting-edge AI infrastructure and training for educators. Establishing robust ICT infrastructure, including high-speed internet and sufficient computing resources, is essential for deploying AI tools effectively. Curricular integration of AI-related competencies in national and state curriculum frameworks promotes equitable access to AI-enhanced environmental education and fosters a generation of environmentally literate citizens equipped to address environmental issues effectively. By implementing these strategies, India can leverage the power of AI to enrich environmental education and cultivate a more sustainable future.

✓ *Finally concluded that*, addressing the environmental impact of AI technologies through education requires a multifaceted approach that integrates life cycle analysis, energy-efficient coding practices, renewable energy integration, responsible recycling, collaborative efforts, and critical thinking development. Conducting comprehensive life cycle analyses of AI hardware enables stakeholders to identify key environmental impact factors and develop mitigation strategies while educating students about these analyses fosters environmental awareness and responsible decision-making. Integrating energy-efficient coding practices into the curriculum empowers students to minimize the energy consumption of AI systems, aligning with broader efforts to promote sustainability in technology development. Teaching renewable energy integration demonstrates practical applications of sustainable practices and aligns AI development with environmental conservation goals. Educating students on responsible recycling and disposal methods reduces electronic waste generation, contributing to sustainable practices in the digital age. Collaborative efforts between policymakers, educators, and industry stakeholders are essential for developing and implementing strategies to mitigate environmental impacts while promoting AI adoption. Fostering critical thinking skills enables students to evaluate the environmental implications of AI technologies and make informed decisions, emphasizing the importance of prioritizing environmental sustainability in technological innovation and education. Integrating these strategies into environmental education curricula can cultivate a culture of environmental responsibility and equip students with the knowledge and skills needed to address complex sustainability challenges in the AI era.

Findings:

The findings from the provided content highlight the transformative benefits of integrating AI-driven technologies into environmental education across various educational levels. These technologies, including virtual simulations, augmented reality (AR) tools, natural language processing (NLP) algorithms, and citizen science initiatives, offer personalized and immersive learning experiences that enhance students' comprehension of complex environmental concepts. By engaging students and fostering experiential learning, these technologies promote deeper insights into topics like climate change, biodiversity conservation, and environmental stewardship. The integration of AI into environmental education fosters critical thinking, problem-solving, and interdisciplinary skills essential for addressing environmental challenges effectively. Through hands-on experiences and real-world applications, students participate actively in environmental research and conservation efforts, contribute to localized datasets, advocate for policy changes, and promote technological literacy. Additionally, AI-driven initiatives bridge educational disparities, promote inclusivity, and empower students from diverse backgrounds to become informed and proactive environmental stewards. The findings emphasize the importance of collaboration between policymakers, educators, industry stakeholders, and communities to develop and implement effective strategies for mitigating the environmental impact of AI technologies. Integrating life cycle analysis, energy-efficient coding practices, renewable energy integration, responsible recycling, and critical thinking development into environmental education curricula promotes environmental awareness and responsible decision-making among students. By prioritizing environmental sustainability in technological innovation and education, these strategies contribute to shaping a more sustainable future for our planet.

Overall, the findings underscore the significant role of AI-driven technologies in enriching environmental education and cultivating a generation of environmentally literate citizens equipped to address complex sustainability challenges in the digital age.

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