Vigyan Varta

An International E Magazine for Science Enthusiasts

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Special Issue 5

7th International Conference on Advances in Agriculture Technology And Allied Sciences"
(ICAATAS 2024)

organized by Society of Agriculture Research and Social Development (New Delhi) & Southern Federal University, Rostov-On-Don, Russia

Venue & Co-Organizing Partner

"*The Neotia University (ICAR Accredited), West Bengal*"

(15-16 September 2024)

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Preface

Vigyan Varta An International E-Magazine for Science Enthusiasts (E-ISSN: 2582-9467) is an online multidisciplinary magazine covering all the domains of science. It publishes all types of writings including popular articles, newsletters, meeting reports, success stories, etc. that undergo a peer review by the strong editorial team that we have. It had its inception in May, 2020 and has successfully completed 5 volumes with 12 issues each year. Currently, the magazine is entering its 6th volume in 2025 and apart from publishing articles, our magazine has also conducted skill development workshops and webinars for the academic community. Vigyan Varta has a vision of creating and developing scientific writing skills and acumen among young researchers.

It's a privilege for us to collaborate and bring out our fifth special issue in the 7th International Conference on Advances in Agriculture Technology And Allied Sciences (ICAATAS 2024)" organized by Society of Agriculture Research and Social Development (New Delhi) & Southern Federal University, Rostov-On-Don, Russia. The conference has given notable insights on varied topics of agriculture and allied sciences and has enabled scientists, students, researchers, and academicians round the country and abroad to bring their work to the forefront.

This special issue highlights articles from diversified fields of agriculture and gives a concise overview of innovative topics to the readers.

We are happy that ICAATAS 2024 has given us a chance to be its media and publication partner and help in popularizing the art of writing popular articles among the scientific community. We look forward to more such informative and insightful special issues in future as well.

Happy Learning!!

Jai Hind.

Suvangi Rath

Miss Suvangi Rath
Founder-Editor & Proprietor
Vigyan Varta

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Future in Focus: Proven Strategies to Reduce Greenhouse Gas Emissions and Tackling Global Warming

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ABSTRACT

Greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are a major driver of climate change, significantly impacting global temperatures, weather patterns, and ecosystems. These gases are primarily emitted from industrial processes, which release CO_2 and CH_4 through fossil fuel combustion and chemical reactions; transportation, which contributes substantial CO_2 and N_2O from vehicle emissions; and agriculture, which produces methane from livestock and nitrous oxide from fertilizer application, along with deforestation that diminishes carbon sequestration. Additionally, waste management practices such as landfills and incineration further exacerbate the problem by emitting methane and CO_2. Effective mitigation strategies include implementing carbon pricing mechanisms like taxes or cap-and-trade systems to incentivize emission reductions, supporting international climate agreements such as the Paris Agreement to

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foster global cooperation and set emission reduction targets, minimizing waste to cut methane emissions, adopting sustainable agricultural practices to reduce methane and nitrous oxide, and investing in reforestation and afforestation to enhance carbon sinks. Integrating these approaches is crucial for addressing greenhouse gas emissions comprehensively and moving towards a sustainable, resilient future.

INTRODUCTION

Greenhouse gases, whether naturally occurring or human-made, absorb and emit infrared radiation, profoundly affecting the Earth's climate. The principal greenhouse gases include water vapor, carbon dioxide, nitrous oxide, methane, and ozone, while human activities also introduce additional compounds like halocarbons other compounds that contain chlorine and bromine, etc. Fossil fuel combustion emission and deforestation exacerbate climate change, leading to more frequent and severe heatwaves, worsening respiratory conditions, and deteriorating air and water quality. These effects heighten the risk of disease, threaten food security, and contribute to extreme weather events that place additional strain on healthcare systems. Reducing greenhouse gas emissions is essential for curbing climate change and safeguarding both public health and environmental sustainability.

What makes CO_2 a greenhouse gas, but not N_2?

The way a molecule vibrates after being struck by an (infrared) IR photon determines its capacity to absorb and re-emit infrared radiation (IR). Some conditions are there for absorption of IR radiation by any molecule-

i. The energy of infrared radiation is transmitted to the molecule vibration at the same frequency during absorption; however, this triggers the vibration to occur at higher energy levels due to an increase in amplitude (Figure 1).

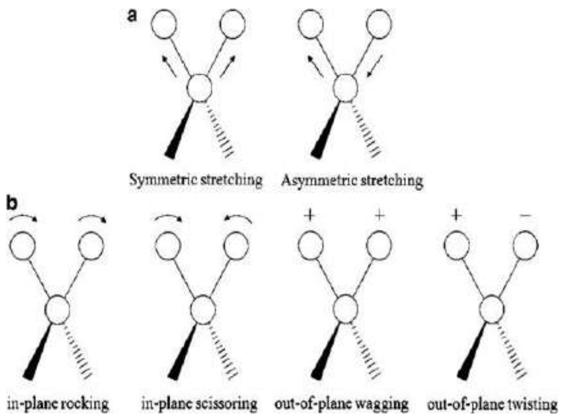

Figure 1. Different type of vibrations by a molecule (a-symmetric and asymmetric stretching, b- rocking, scissoring, wagging and twisting) (Source-Ojeda and Dittrich, 2012)

ii. At the moment infrared radiation (IR) is incident to a substance, the electric field of the radiation exerts forces on the molecular charges. As opposite charges are always exerted in opposite directions, this tends to cause the molecule's dipole moment to oscillate at the radiation's frequency. If the dipole moment's oscillation brought on by molecule vibration is the same as the oscillation of dipole moment induced by IR radiation; molecules absorb infrared radiation at that specific frequency causing an increase in the amplitude of its own vibrational energy.

iii. The more the changes in dipole moment during a vibration, the more easily the photon electric field can activate that vibration. If a molecular vibration should not result in a change in the dipole moment, then a forced dipole moment oscillation cannot initiate the vibration. As a result, the symmetric vibration of CO_2 or N_2 cannot absorb infrared radiation.

iv. The interatomic distance is affected by molecular or atomic vibrations because the movement, known as oscillation, causes the atoms to periodically shift in relation to one another. The frequency of vibration obeys the *law of simple harmonic motion*, which is formulated as follows:1

$$V = \frac{1}{2\pi c\sqrt{k/m}}$$

Where, V=frequency of vibration (cm^{-1}); c= velocity of light in vacuum; m= reduced mass of thevibrating atoms; k= force of constant (dynes cm^{-1})

What is greenhouse gas effect?

Radiation from the atmosphere and also from the bottom of the earth surface is released to all the directions, which is trapped within the surface-troposphere system by greenhouse gases. It is referred as the natural greenhouse effect (Figure 2). Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. In general, temperature in the troposphere drops with height. Effectively, the source of Infrared radiation emitted into space is originating at an elevation where the average temperature is -18 °C (https://web.archive.org/web/20050112211604/http://www.giss.nasa.gov/research/briefs/ma_01/), proportionate to the net amount of solar radiation received, yet keeping the earth's surface at typically 14°C (Karl and Trenberth,2003).

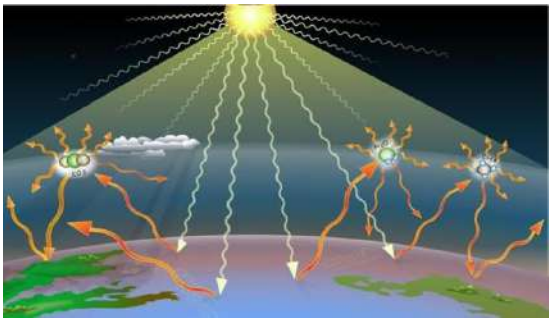

Figure 2. Greenhouse effect in the atmosphere

(Source- https://commons.wikimedia.org/wiki/File:Greenhouse-effect-t2.svg)

Increasing the concentration of greenhouse gasses result in a higher infrared opacity of the atmosphere, leading to an actual radiation entering lower temperature and from a higher height in space. As this generates a radiative forcing, an imbalance that is exclusive to somewhat offset by an increase in the temperature of the surface–troposphere connection. This is referred as "*enhanced greenhouse effect*".

Concentration of greenhouses gases in the atmosphere:

Among the greenhouse gases, CO_2 provides a major contribution in global warming. Charles David Keeling from Scripps Institution of Oceanography, University of California, USA was the first to man who regularly recorded the atmospheric CO_2 concentrations in Antarctica and on Mauna Loa, Hawaii from March 1958 onwards. He developed a graph, known as *keeling curve* (Figure. 3), based on the accumulation of CO_2 in the atmosphere continuously measured at Mauna Loa Observatory on the island of Hawaii from 1958 to the recent day. The Keeling Curve displays a cyclical variation of roughly 6 ppmv (parts per million by volume) annually, which is indicative of the seasonal variations in the global land vegetation's uptake of CO_2. The amount of CO_2 drops during the northern spring and summer as new plant growth removes CO_2 from the atmosphere through photosynthesis, with a maximum observed in May. After reaching a minimum in September, CO_2 levels rise again during the northern fall and winter as plants and leaves wither and decompose, emitting carbon dioxide back into the atmosphere. The Keeling Curve indicates that as of 15th May 2024, the average monthly concentration of carbon dioxide in the atmosphere was 425.22 ppm. Concentration of other GHGs is given in the figure 4, a-e.

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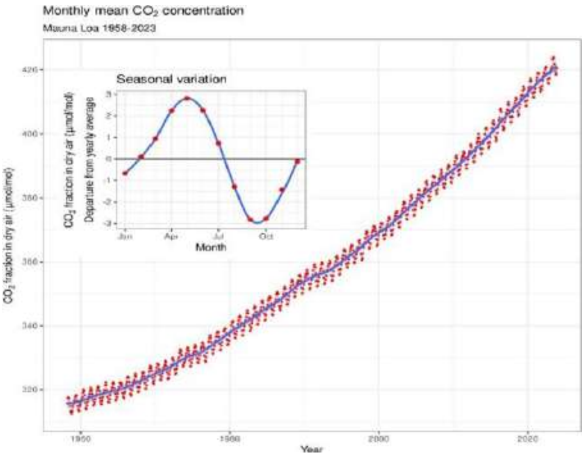

Figure 3. Concentration of carbon dioxide gas with time, keeling curve (Source- https://en.wikipedia.org/wiki/Greenhouse_gas)

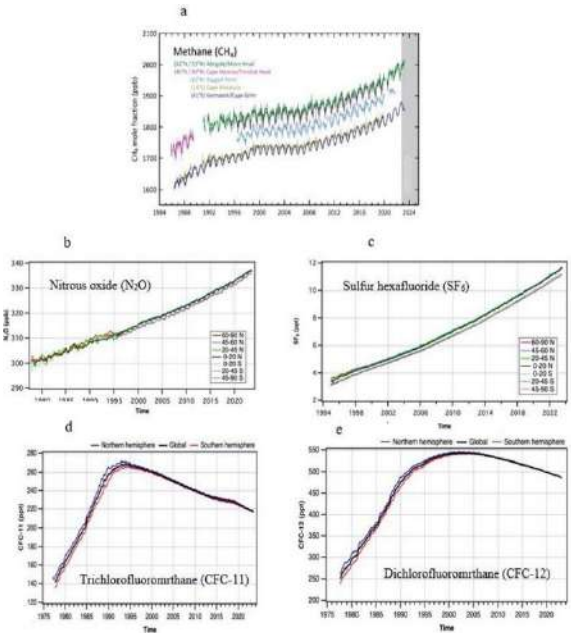

Figure 4. Concentration of different greenhouse gas with time [a- CH_4 Vs. time (N- North, S- South), b- N_2O Vs. time (N- North, S- South), c- SF_6 Vs. time (N- North, S- South), d- CFC 11 Vs. time, e- CFC 12 Vs. time]

Source- a. https://agage.mit.edu/data/agage-data
b. https://www.esrl.noaa.gov/gmd/hats/combined/N2O.html
c. https://gml.noaa.gov/hats/combined/SF6.html
d. http://www.esrl.noaa.gov/gmd/hats/combined/CFC11.html
e. https://www.esrl.noaa.gov/gmd/hats/combined/CFC12.html

Greenhouse gas emission from different countries and sectors:

The top three GHG emitters countries are China, the United States and India, contribute more than 45% of total emissions, India ranks 3rd in emission of greenhouse gas after China and United states of America in the year of 2023 (Figure 5). Change in land use system and forestry caused higher GHG emission in the world followed by agricultural practices (Figure 6). In India also, agriculture sector ranked 2nd in GHG emission after power generation sector (Figure 7).

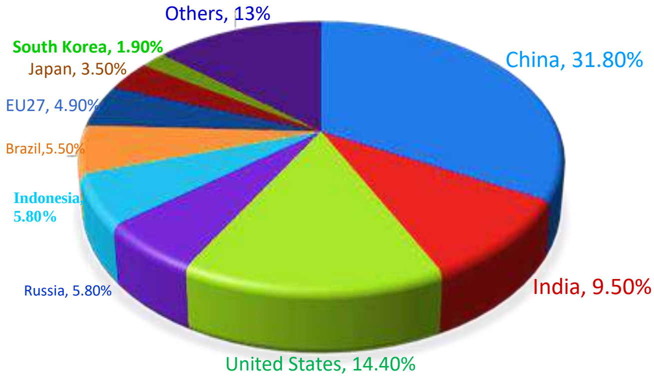

Figure 5. Contribution of different countries in greenhouse gas emission in the year of 2023 (Data source- https://sigmaearth.com/global-carbon-emissions-country-by-country-for-2023/)

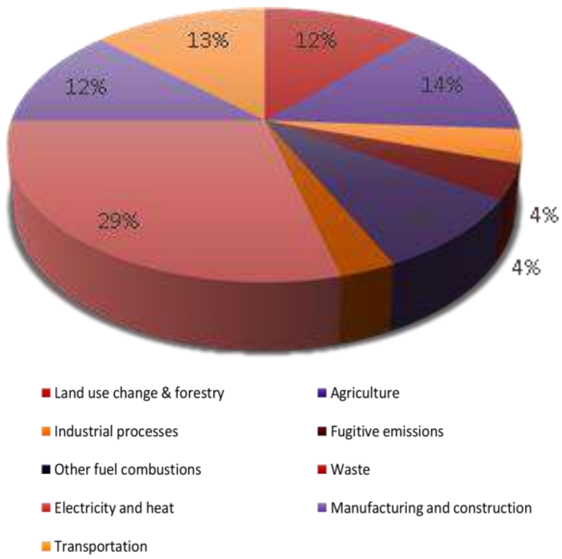

Figure 6. Contribution of different sector in greenhouse gas emission in world (Data source- Tee, 2011)

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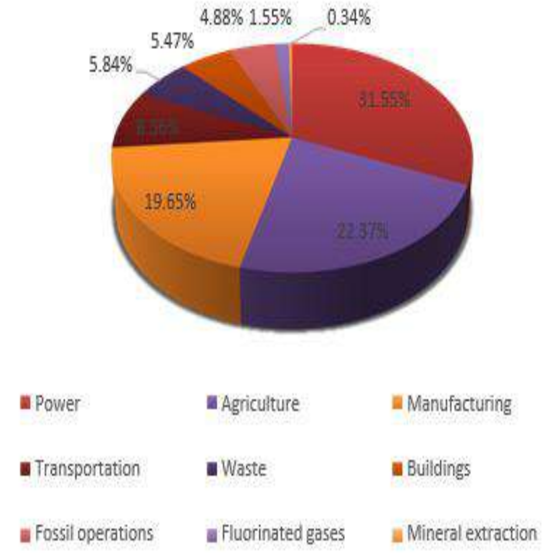

Figure 7. Contribution of different sector in greenhouse gas emission in India (Data source- https://www.statista.com/statistics/955980/india-distribution-of-ghg-emissions-by- sector/)

Effect of greenhouse gas emissions on environment

The greenhouse gases affect the ecosystem of earth crust by influencing either directly or indirectly the each and every activity. The main effects of increased greenhouse gases are:

Global warming: The phenomenon refers to the gradual rise in the Earth's average atmospheric temperature, primarily driven by the accumulation of gases like carbon dioxide and methane which are the primary causes of global warming. These gases are largely emitted through the combustion of fossil fuels, vehicular exhaust, industrial processes, and other anthropogenic activities, making this a significant environmental concern. Increased concentrations of greenhouse gases like carbon dioxide, methane, and nitrous oxide in the atmosphere directly contribute to a positive radiative forcing, enhancing the effect of green house and causing global warming (Figure 8).

Depletion of ozone layer: The ozone layer acts as a protective shield for the Earth by absorbing harmful ultraviolet (UV) radiation from the Sun. It is located in the lower stratosphere. Depletion of this layer allows increased UV radiation to arrive the Earth's surface, which can cause to adverse effects such as an elevated risk of skin cancer and significant alterations in climate. The primary driver of ozone layer depletion is the accumulation of certain greenhouse gases, including chlorofluorocarbons (CFCs), carbon dioxide, methane, and others.

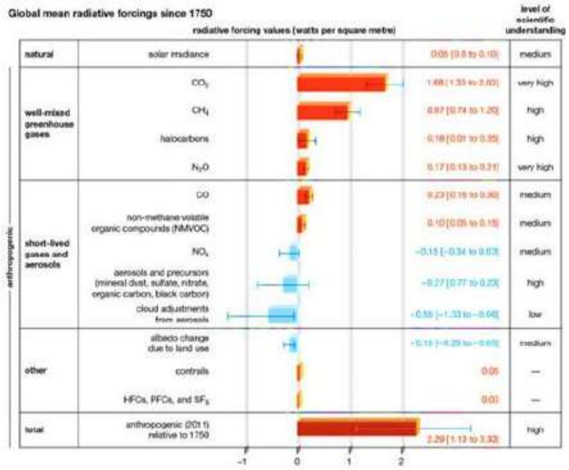

Figure 8. Positive and negative radiative forcing (Source- https://www.britannica.com/science/radiative-forcing)

Climate change: Emissions of greenhouse gases profoundly affect climate change by trapping heat in the Earth's atmosphere. Gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) create a "greenhouse effect" by absorbing and re-radiating infrared radiation that would otherwise escape into space. This process leads to a gradual increase in global temperatures. Consequently, we face more frequent and severe weather events, including heatwaves, prolonged droughts, and intense storms. Additionally, rising temperatures accelerate the melting of polar ice caps, which contributes to rising sea levels and disrupts natural ecosystems. In essence, Greenhouse gas emissions fuel global climate change and climate instability, posing significant risks to both environmental and human systems.

Desertification: Greenhouse gas emissions drive desertification by intensifying global warming and altering climate patterns. Heightened CO_2 levels raise temperatures and shift precipitation, reducing soil moisture and making it harder for vegetation to grow. This can transform once- fertile lands into arid, barren areas, accelerating desert expansion. Increased temperatures also lead to more frequent droughts and extreme weather, further degrading land quality. Overall, these emissions significantly contribute to desertification, affecting agriculture, water resources, and biodiversity.

Smog and air pollution: Smog is a mixture of smoke and fog, formed through a combination of natural processes and human activities. It typically arises from the accumulation of greenhouse gases and pollutants like nitrogen oxides (NO_x) and sulfur dioxide (SO_2), which interact with sunlight to create a dense, harmful haze. This haze can reduce air quality and visibility, posing serious health risks and contributing to environmental damage. Urban areas with high increase level of industrial activity and vehicular emissions are particularly vulnerable to severe smog conditions.

Acidification of water bodies: Increased greenhouse gases have led to the acidification of many of the world's water bodies. When these gases, particularly carbon dioxide (CO_2), dissolve in rainwater, they form carbonic acid, which decreases the pH of water. This acidification harms aquatic life by disrupting ecosystems, damaging coral reefs, and affecting the health of fish and other marine organisms. As a result, the delicate balance of aquatic environments is threatened, impacting biodiversity and the overall health of marine ecosystems.

Strategies to reduce greenhouse gas emission:

Promote renewable energy: In nations that implement carbon pricing has been widely adopted, it has effectively driven businesses to reduce their emissions. Additionally, in regions with supportive regulatory frameworks and monetary incentives for renewable energy sources development, establishing bold renewable energy goals has proven highly successful.

Fertilizer use and crop yield enhancement: Enhancing the productivity and efficacy of nitrogen use in crops can significantly reduce N_2O emissions by lowering the accumulation of residual NO_3–N in the soil. This not only reduces greenhouse gas emissions but also enhances soil health and reduces the environmental impact of fertilizer use. By optimizing nitrogen application, we can achieve a dual benefit: addressing climate change by decreasing N_2O emissions and promoting sustainable agricultural practices.

Commercial fertilizer sources: N_2O emissions tend to be lower with NO_3- based fertilizers compared to NH_4+ based fertilizers, as well as organic or synthetic-organic sources. Nevertheless, research has demonstrated that anhydrous NH_3 often results in higher N_2O emissions in comparison to other nitrogen sources. (Breitenbeck and Bremner, 1986; Venterea *et al.*, 2005).

4R stewardship: Optimize the combinations of nitrogen source, application rate, placement, and timing to enhance crop yields and farmer profits while minimizing the overall greenhouse gas emissions linked to the specific local crop and soil system.

Use of slow and controlled released fertilizers: Controlled-release technologies, which manage the timing of nitrogen release from fertilizers, can help decrease NO_3-

leaching, NH_3 volatilization, and N_2O emissions.

Reduction in greenhouse gas emission from agriculture: No-tillage and residue return practices can significantly lower the greenhouse gas emission intensity in double-cropping rice systems. No-tillage helps to preserve soil carbon, lowers the need for agricultural machinery, reduces fossil fuel consumption therefore cuts off CO_2 emissions. Additionally, it effectively decreases emissions of CH_4 from paddy field also (Figure 9).

Encourage reforestation and afforestation: Reforestation and afforestation are efficient approaches for addressing greenhouse gas emissions through the restoration and expansion of forest cover. Large-scale planting efforts can offset emissions from sectors like industry and transportation by sequestering substantial amounts of CO_2.

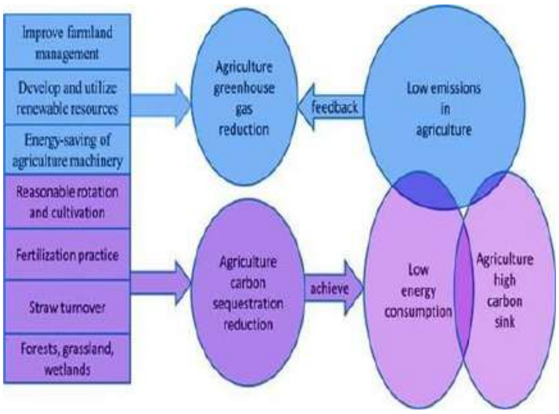

Figure 9. Agricultural greenhouse gas emission reduction model (Source- Liu *et al.*, 2019)

Promote sustainable agriculture: Promoting sustainable agriculture is efficient for reduction of greenhouse gas emissions, particularly methane (CH_4) and nitrous oxide (N_2O), which are often produced by conventional farming practices. Sustainable agriculture emphasizes techniques that enhance environmental health, boost biodiversity, and minimize chemical inputs. A key approach is adopting organic or natural farming methods, which avoid synthetic fertilizers and pesticides, thereby reducing nitrous oxide emissions.

Minimize waste: Minimizing waste is an efficient strategy that reduces emission of greenhouse gas, particularly methane (CH_4) and carbon dioxide (CO_2), which are released from landfills and waste incineration. By decreasing the amount of waste sent to landfills, we can significantly lower the methane emissions resulting from the anaerobic decomposition of organic materials.

Biofuels: Use biofuels, like ethanol or biodiesel, which are derived from renewable sources and generally emit less GHG compared to conventional fossil fuels.

Adopt carbon pricing: Adopting carbon pricing is a powerful economic strategy for reducing greenhouse gas emissions by assigning a financial cost to carbon emissions. This approach encourages businesses and individuals to lower their carbon footprints. Carbon pricing can be implemented through two main mechanisms: carbon taxes and cap-and-trade systems.

Support international climate agreements: Supporting international climate agreements is crucial for reducing greenhouse gas emissions globally. These agreements unite countries to collaboratively tackle climate change, establish emissions reduction targets, and distribute responsibilities. A key example is the Paris Agreement, adopted in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC).

Protocol related to greenhouse gases: it was established in 1997 for reduction of emission of greenhouse gas, with excluding ozone depleting substances. The Kyoto protocol encourages countries to begin lowering greenhouse gas emissions where it's most cost-effective, such as in developing countries. The

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1985 Vienna convention was developed by the United Nations Environment Programme (UNEP) to protect the ozone layer and human health from its harmful effects. In 1987, Montreal protocol was signed in Montreal, Canada, to gradually eliminate the production and consumption of ozone-depleting substances. The Kigali Amendment, which was added in 2016, also regulates hydrofluorocarbons, which are greenhouse gases that are used as a substitute for ozone-depleting substances. The Vienna convention (1985) for the protection of the ozone layer and the Montreal protocol (1987) on substances that deplete the ozone layer do not directly tackle the challenge of climate change. However, they do seek to phase out chlorofluorocarbons (CFCs) and halons, an important group of greenhouse gases.

CONCLUSION:

In conclusion, tackling the emissions of greenhouse gas is not just a necessity but an opportunity to shape a healthier planet and a more sustainable future. By integrating innovative strategies like carbon pricing, international climate agreements, waste reduction, sustainable agriculture, and reforestation, we can turn the tide on climate change. Embracing these approaches will not only cut emissions but also foster a resilient environment, drive economic growth, and enhance the quality of life for generations to come. Together, we have the power to create a lasting impact and build a world where both people and the planet can thrive.

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New Approaches for Farmer Wellness and Its Effects on Rural Life

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ABSTRACT

Farming has always played a crucial role in India, being one of the leading agricultural producers globally. The country is renowned for being the largest producer of okra, milk, and spices. However, agriculture is highly vulnerable to the unpredictability of weather conditions, which can lead to crop failure, posing significant challenges and distress for farmers. In response, the Indian government has implemented numerous schemes to support farmers. Yet, amidst issues such as low crop yields and mental health struggles within rural communities, some farmers ultimately succumb to the pressures, tragically taking their own lives.

INTRODUCTION

India and agriculture go long back to ancient times, as it has always been an important aspect of India's growth and prosperity. From the ancient scriptures and books, it is evident that people also had great knowledge of proper methods and techniques of growing crops during the ancient times. Today, India is also well known for its crop production as it is the largest producer of crops like okra, pulses, jute, milk etc. India is also known as the land of spices as it is the largest producer, consumer and exporter of spices. With almost 60% of total land available in India under cultivation and almost 55% of India's population sole source of income is through agriculture; despite having such a huge chunk of land and population in this field the income generated by many of the

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farmers is much less than the expenses spent on all the things used for cultivation. In many parts of India subsistence farming (All the crops gowned or livestock raised is consumed by the farmer and his family) is practised which is due to the low yield of the crop or due to small land holding by the farmers, and due to this low earning and yield, many farmers take their own many life each year. This has become a major hurdle in the field of agriculture and many private and public bodies are constantly trying to help the farmers and solve their problems so they do not seek to these extreme conclusions. To solve this problem many banks like the Regional Rural Banks give loans to the farmers at low interest and the government of India has also introduced many schemes and plans for the welfare and profit of the farmers.

Objective and Research Methodology

This study has been carried out to inspect how the new approaches and schemes introduced by the government and other agencies affect rural people. The study is based on secondary data to achieve its objective. The secondary data is sourced from different websites, scholarly articles, and books.

Schemes Developed by the Indian Government for the Welfare and Wellness of Farmers

During this past decade, the government of India has released many schemes for the welfare of the farmers and the people living in rural places. Some of these schemes and their benefits include:

- Pradhan Mantri Kisan Samman Nidhi (PM-KISAN)- It is a central sector scheme launched on 24th February 2019 that provides financial aid to marginal farmers. Under this scheme, an amount of Rs. 6000/- per year is provided in three equal instalments to the registered farmer bank accounts.

2.8 lakh crores have been transferred through Direct Benefit Transfer to more than 11 crores beneficiaries.

- Pradhan Mantri Kisan MaanDhan Yojana (PM-KMY)- It is a central sector scheme launched on 12th September 2019 that provides old age protection and social security for small and marginal farmers. The applicants between the ages of 18 to 40 years can contribute an amount of Rs. 55 to Rs. 200 each month till they reach the age of 60, after which they get a monthly pension of Rs 3000.

So far 23.38 lakh farmers have enrolled in this scheme.

- Pradhan Mantri Fasal Bima Yojana (PMFBY)- PMFBY works on 'One Nation, One Crop, One Premium. It was launched in 2016 and provides insurance to farmers in case of natural calamities like crop failure due to drought, pest attack etc.

A total of 5549.40 lakh farmer applications were insured due to this scheme.

- Agricultural Infrastructure Fund (AIF)- It is also a central sector scheme that provides medium to long-term financial debt for the construction of post-harvest management infrastructure and community farming assets.

Impact and Results of These Schemes

As indicated earlier, the various schemes and the number of beneficiaries demonstrate the significant impact of these new initiatives on farmers and rural communities. There are even more schemes that play a crucial role in improving people's lives, beyond those mentioned. Despite these schemes offering substantial benefits, the suicide rate among farmers in India continues to rise. Notably, there was a significant increase in suicides in 2021 and 2022, with reported numbers of 10,881 and 11,290, respectively. This rise can be attributed to the mental stress caused by the lockdown and the COVID-19 pandemic. While these figures are lower than those from a decade ago, the annual suicide rates are still on the rise. Despite the considerable benefits provided by these schemes, some individuals, due to unpredictable circumstances, tragically take their own lives.

CONCLUSION

The welfare of farmers has always been a crucial aspect of the agricultural sector in India, and the government's various schemes play a significant role in ensuring their well-being. Despite the benefits derived from these schemes, they do not address all the challenges faced by farmers and rural communities, as evidenced by the persistently high suicide rates in India. Therefore, it is imperative to not assess these schemes solely based on the number of beneficiaries, but also consider their impact on mental health. Mental health awareness, which has long been a taboo subject in India, should be a priority, and existing schemes should be evaluated in terms of their support for this crucial aspect. Introducing additional schemes that focus on mental well-being would be beneficial.

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Artificial Intelligence in Agriculture: Advances, Challenges, and Future Directions

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ABSTRACT

Artificial Intelligence (AI) is revolutionizing agriculture by converting conventional methods into efficient, data-driven solutions. This article examines the progress in AI applications in agriculture, highlighting precision farming, autonomous machinery, and predictive analytics. Through the integration of technologies like machine learning, IoT, and big data, AI has augmented decision-making, refined resource management, and maximized production. The implementation of AI technology, such as intelligent irrigation systems and AI-based crop disease identification, has facilitated sustainable and eco-friendly agricultural practices. Despite significant progress, there are still challenges such as high implementation costs, concerns about data privacy, and insufficient infrastructure in remote areas, which hinder widespread use. This article emphasizes the capacity of AI to tackle global issues such as food security and climate change while proposing future avenues for the integration of AI with new technologies like blockchain. We advise a cooperative, multidisciplinary strategy to connect technology advancement with practical implementation in agriculture.

INTRODUCTION

AI in agriculture refers to the use of advanced computational technologies and machine learning techniques in order to improve the different processes of farming and food production. These AI-based systems can process enormous volumes of data gathered from sensors, satellites, and UAVs, to help the farmers and other agricultural specialists in understanding the real-time crop health These complex devices are useful in achieving the concept of precision agriculture, which include efficient and proper distribution of resources, efficient control of pests and diseases and better estimation of crop yields. Furthermore, the use of AI Robotics and Autonomous machinery in farming has led to the cutting down on costs of labor while enhancing efficiency especially in planting, harvesting, and sorting processes. This involves the application of these systems that are able to analyze data, reason and even act to solve problems and perform various tasks that were hitherto done by human beings in agriculture. AI use in agriculture is rather diverse and it covers the whole range of aspects, such as precision farming and crop management, machinery control, and analytics. These technologies help the farmers to manage the available resources to the maximum, improve the production of crops and make proper choices in dealing with issues like climate change, use of pesticides and the general issue of hunger in the world. Thus, applying the advanced AI technologies (Kayastha et al., 2024) the agricultural industry will be able to increase the measures of sustainability, effectiveness, and productivity in view of the growing world This therefore includes in the use of Artificial Intelligence in agriculture, this includes the creation of robots to carry out tasks like harvesting and weeding in order to cut down on costs. In addition, the application of artificial intelligence technologies is capable of identifying the patterns of satellite images and soil data and, therefore, improve the efficiency of irrigation and fertilization as well as reduce water and nutrient usage (Debnath & Kumar Basu, 2023). Such developments not only increase the production of agricultural output but also help in coming up with measures that help in the preservation of the environment as they reduce on wastage of resources and effects of farming on the environment.

A brief background of the use of artificial intelligence in agriculture

It may be worth noting that the development of artificial intelligence in the sphere of agriculture has been significant in the last few decades.

1960s-1970s: First generation of the expert systems was designed for crop management and disease diagnosis.

The 1980s: Some of the agricultural related problems like yield estimation and pest detection have started using machine learning techniques.

1990s: This paper integrated Artificial Intelligence (AI) with Geographic Information Systems (GIS) and remote sensing in the precision farming.

2000s:

- Automation through the use of artificial intelligence was used in implementing agricultural tasks such as picking fruit and getting rid of weeds.

- Higher level crop monitoring systems employing computer vision have been proposed and developed.

2010s:

- The use of big data in agriculture has been developed in the recent past.

- AI has been applied in the weather prediction and climate simulation.

- There are smart greenhouses and artificial intelligence (AI) in irrigation systems among others.

2020s:

The application of AI was incorporated with IoT in order to monitor the farms in real time.

Application of the Al drones for crop monitoring as well as pesticide spraying has improved a lot.

-Cnn was used in the identification of crop diseases and the evaluation of the soil condition.

Why AI is helpful in Agriculture

Increased Efficiency and Productivity: It means that farmers can manage the resources efficiently with the help of advanced applications of Artificial Intelligence, which leads to higher crop yield and efficient functioning of the farms (Sharma et al., 2024). These technologies have also helped in providing a better and timely management of the crops such as pest control at a particular time as well as irrigation at a right time. Moreover, AI helps in decision making in agriculture through data analysis and prediction to enable farmers make the right decisions regarding planting, harvesting and market strategies (Mishra et al., 2024). Many improvements in the design of autonomous agricultural machinery have been attributed to AI technologies which have helped in cutting down costs on labor and increasing efficiency. In the same manner, AI-enable Predictive Maintenance has helped farmers in reducing the time the equipment stands still as well as improve its efficiency. These technologies have not only helped in the increase of productivity but have also made it possible for the agricultural professionals to work on larger sized farms with a high degree of accuracy and less human interference.

Improved Crop Yields: This has been made possible by the technological advancements especially in AI that has helped in the monitoring of plant health and soil status as well as the prevailing weather conditions. These new technologies facilitate the identification of upcoming problems like nutrient deficits or pest problems and help the farmers to act in advance (Panchal & Jain, 2024). Also, advanced AI-based solutions can help farmers determine the best planting techniques, the correct application of fertilizer and the most suitable irrigation intervals, which contributes to the more efficient use of resources, and, therefore, to higher yield. These artificial intelligence systems are also helpful in the application of precision agriculture practices such as variable rate application of inputs thus conserving resources. More so, machine learning can use past yield data and environmental data to determine the most suitable time to plant and the right crop to grow at the right time thus increasing the overall productivity of a farm. In addition, machines powered by Artificial Intelligence and robotics are already being developed for the purpose of performing jobs that hitherto required human input such as, planting and weeding, which may help solve the problem of human resource in the agricultural

Better Resource Management: The use of artificial intelligence (AI) in decision support systems has greatly influenced the way resource management is done in agriculture, thereby allowing agricultural experts to come up with the best ways of using water, fertilizers and controlling pests. Such advance systems can provide right time of irrigation based on the soil moisture status and weather report so that water is well conserved and crops grown in the best possible manner (Panchal & Jain, 2024). Also, through the use of artificial intelligence there is the ability to establish the previous year's harvest records and market trends to help in designing proper crop rotation schedules and to determine the most profitable crop types for the certain area.

Enhanced decision-making: These technologies also enhance productivity while at the same time promoting sustainable farming that has low effects on the environment. In addition, the use of AI in the automated control of farm machinery and equipment has improved on precision, minimized human interference and enhanced production. Use of AI technology in livestock management system helps in improving the accuracy through the use of smart sensors and data analysis. These tools are used in the assessment of the health of animals, efficient feeding of the animals and even in the identification of the right time for breeding. In addition, the AI algorithms are useful in identifying the market trends and weather condition hence helping farmers in choosing the right crop to cultivate and the right time to harvest (Kumari & Muthulakshmi, 2024). This approach could therefore have the potential to enhance profitability while at the same time minimizing wastage. The combination of AI with other growing technologies like blockchain and IoT enhances the end-to-end tracking and tracking protocol, enhancing the food supply chain and alleviating consumers' worries about food safety and its source (Jabbar et al., 2024).

Applications of AI in Agriculture

Precision Farming: It is evident that this technology is not limited to crop production but also is used in livestock production. In this domain, AI based systems are used in the assessment of health status of animals and identifying diseases at an early stage and management of feeding regimes (Kumari & Muthulakshmi, 2024). Also, the AI algorithms can have a look at the satellite images and the drone videos which will enable its users to come up with a general review of the health of crops in large fields. This enables the agricultural professionals to know the areas that are affected and in turn come up with measures that can help in sorting out the problem. Also, the AI controlled robotic systems are being developed for the modern-day agriculture practices such as planting and ironing, weeding, and even sorting. These innovations have the potential of greatly decreasing employment costs in the agricultural sector and increase the productivity of resources used in the farming activities. Some of the applications of AI in agriculture include precision farming which helps farmers to allocate the right inputs and minimize on the adverse effects on the environment. These modern tools are able to analyze the soil, climate and the previous crop production history so as to offer specific suggestions on matters concerning planting, water and food supplies. In addition, predictive analytics that are based on artificial intelligence are being used to predict future market trends and price changes of commodities to help the agricultural experts to decide the most appropriate time and type of crop to grow and enter the market (Kumari & Muthulakshmi, 2024).

Source: corcel.io

Livestock Monitoring: The use of artificial intelligence in Unmanned Aerial Vehicles and satellite imagery in crop and livestock, disease control has been enhanced as well as early intervention and treatment (Wu, 2024). Artificial intelligence techniques are being applied in the generation of new crop varieties with improved resistance and productivity; accelerating the conventional breeding techniques and solving the food crisis issues. Also, modern agricultural structures that involve use of AI driven robotic systems in activities like picking of fruits and weeds control with precision to minimize the use of manual labor and minimize the use of hazardous pesticides. AI based technologies have not only transformed crop management but have also penetrated into livestock farming. Sensors and wearable devices with artificial intelligence capabilities make it possible to track the health, behavioural and production status of individual animals in real-time and consequently, these advanced methods of farming not only ensure better care of animals, but also help in the improvement of the livestock production systems, to reduce the adverse impacts of agriculture on the environment and the effective use.

Source: corcel.io

Crop Disease Detection and Prevention: The use of artificial intelligence is employed in the detection of early symptoms of crop diseases through image recognition and this assists farmers to intervene before the crops are invaded (Lavanya & Krishna, 2022 These systems use images of crops at a very high resolution and are capable of identifying changes in colour, texture or shape of the leaves which may be signs of the diseases. AI in disease detection fast forwards the process of intervention and helps in preventing the loss of crops and reduces the need for excessive chemical treatment making it more efficient to practice sustainable agriculture. The technology in focus goes beyond tracking specific animals to include herds to help professionals in the agriculture sector to make informed decisions on breeding, gene choice, and overall management of the herd (Lavanya & Krishna, 2022). Also, artificial intelligence can incorporate environmental factors which include temperature, humidity and air quality to enhance the comfort of the animals and avoid stress factors that may in turn affect health of the animals and productivity. In the area of crop disease identification, machine learning models are now being created for disease prediction using past records, climate, and other factors so that appropriate management strategies can be employed and farming practices changed in advance.

Source: corcel.io

Smart Irrigation Systems: Agriculture is one of the most sensitive sectors that has been transformed by the use of smart irrigation systems that are powered by Artificial Intelligence. These systems are capable of altering the irrigation time and water supply in the fields depending on the existing conditions hence conserving water and increasing crop production. In addition, the smart irrigation technology can be combined with other precision agriculture technologies to form an efficient and complete farm management system which enhances the effectiveness and efficiency (Ahmed & Gutub, 2015). Pest monitoring and management can be integrated into advanced AI systems as a part of the complex system that can identify and track the potential pest outbreaks using the image recognition and machine learning algorithms. Furthermore, through analysis of big data including soil characteristics, weather conditions and market trends, AI can help agricultural experts in decision making as to the time to switch crops, the type of fertilizer to use and when to harvest (Balbis & Jassim, 2018). These broad farm management approaches not only increase production standards but also pave way to environmentally healthy farming activities.

Source: corcel.io

Problems and Constraints of AI Implementation in Agriculture

High Cost of Implementation: A major challenge emanating from the integration of AI-driven agricultural systems is the capital cost that is needed for their deployment which may be a Herculean task for small farmers and especially those in the developing world. These costs are not only restricted to the necessary hardware and software but extend to include training as well as other infrastructure developments. Furthermore, the increasing need to maintain these advanced systems and the need to update them from time to time may be expensive and may thus hinder their adoption across the different agricultural settings.

Data Privacy and Security Concerns: The adoption of artificial intelligence in the field of agriculture has implications on the data ownership, privacy and security issues. Some concerns that can be raised by the agricultural professionals include; revealing of sensitive operational information, crop yield information, and financial records to the AI systems and third-party service providers. In addition, there are concerns that exist on the likelihood of cyber threats that may compromise the agriculture data of farmers and the industry as a whole.

Limited Infrastructure and Connectivity in Rural Areas: The integration of artificial intelligence in agriculture results in the need for improved and strong internet connection and an adequate digital platform, which may not be readily available in many rural and remote farmland (Rosnan & Yusof, 2023). This means that the small-scale farmers and those in the remote areas may not be able to access these new methods of farming and hence the benefits of implementing AI in agriculture may be limited by geographical location or scale of farm. However, the constraints which may include the unreliable power sources and technical support in these areas may limit the effectiveness of implementing and maintaining the AI systems.

Lack of a Skilled Workforce: One of the major challenges which hinder the extensive use of AI technologies in the agricultural sector is the lack of experts with a combination of agriculture and artificial intelligence knowledge. This core competency gap does not only affect the farmers and extension workers, but also the technicians, data analysts, and the artificial intelligence experts who should be able to define, design, as well as maintain such complex systems within the Moreover, the fast rate of developments in the AI technology may outpace the ability of schools and training to provide the needed personnel with adequate knowledge and skills to apply such advancement in the agriculture sector.

CONCLUSION

Incorporation of artificial intelligence in agriculture has several implications that are not only technological. To overcome these barriers, it is necessary to employ a more complex strategy which involves various players, including the authorities, universities, and businesses. With these changes happening in the agricultural sector, there is a need to come up with proper plans that can help in closing this gap between technology and the real-world use of agriculture by farmers and the rural people. This has created a need to embrace a more holistic and interdisciplinary approach to these issues that can only be adequately tackled through collaboration of various disciplines such as computer science, agronomy, environmental science and the social sciences. This partnership should concentrate on the creation of specific set of AI technologies platforms which can enhance the efficiency of agricultural production yet, taking into consideration the specific social and ecological conditions of the farming communities. Thus, the formation of cooperation between technology producers, agrarians, and local actors makes it possible to create advanced AI-based agricultural systems that are beneficial both for large enterprises and small farmers.

Future of AI in Agriculture: Applying AI technologies in the agricultural sector presents a positive approach toward precision farming approaches which can help the agricultural experts in managing the resources carefully and reducing adverse effects on the environment. These technological advancements can help in improving the water management technologies, implementing the effective pest control measures and increasing the efficiency in estimating crop yield. Furthermore, AI based decision support systems can help the farmers to get accurate information at right time so that they can make proper decisions in terms of planting, harvesting and even in analysing the market trends.

Call to Action for Adopting AI in Agriculture: This will be achieved through artificial intelligence (AI) which is fast improving and is predicted to revolutionize crop breeding programs to come up with crops that are more productive and tolerant to certain environments. Also, the AI-based self-governed farming machinery and robotic technology can help in filling in the gaps created by the deficit of workers in the farming industry as well as improving the productivity and reduced risk of carrying out dangerous operations. Other examples of how AI can be combined with other emerging technologies like blockchain and IoT can also enhance the traceability and accountability in the agricultural supply chain hence enhance food safety and build consumers' confidence.

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Plant Microbe Interactions: Using the Power of Beneficial Microbes for Enhanced Crop Growth

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ABSTRACT

Plant development, health, and production are all greatly impacted by interactions among the microbiota and the plant. Both symbiotic and antagonistic interactions exist between plants and microbes, and understanding both types of interactions is crucial for improving agricultural productivity and practices. Understanding the intricate structural as well as functional richness found in plant microbiomes is essential to realising the enormous potential of these systems in agriculture. We provide an overview of the ways in which interactions between plant microbiomes affect the advantageous characteristics of the host, especially nutrient uptake and defence, as well as potential agricultural uses.

INTRODUCTION

Sustainably producing crops is going to be a major issue in the 21st century. Due to climate changes, a decrease in agricultural land, and rapid urbanization, the use of synthetic chemicals inappropriately has significantly deteriorated soil health and crop productivity. So, mitigating the problem and increasing sufficient food production for a growing population is a challenge. To solve this issue new technological inventions are necessary with sustainability. Thus, one of the best options is to maximise the use of plant-microbe interaction for crop production. Microorganisms that reside in the phyllosphere above ground and the rhizosphere below it coexists with plants. They exist as endophytes inside plants, as epiphytes affixed to plant surfaces, and in the soil surrounding the roots. These microbes may affect plants' growth and well-being in a beneficial, neutral, or detrimental way. Utilising microorganisms' ability to improve crop output and plant nutrient quality is a key tactic in climate-smart agricultural practices.

Plants and microbes can interact in a variety of ways, from positive ones (such as nitrogen fixation, nutrient distribution, and plant defence) to plant-pathogen interactions (which cause bacterial, fungal, and viral diseases in plants).

1. Symbiotic Nitrogen Fixation

- **Rhizobia:** These are a type of bacterium that forms nodules on the roots of legumes (such as beans, peas, and soybeans) and converts atmospheric nitrogen into a form that plants can use. The utilisation of synthetic nitrogen fertilisers is so diminished.

- **Frankia:** a distinct genus of nitrogen-fixing bacteria that donates nitrogen to non-leguminous plants like alder and casuarina through collaborative partnerships.

2. Mycorrhizal Fungi

- Arbuscular mycorrhizal fungi (AMF): By expanding the root network into the soil, these fungi improve nutrient absorption, particularly phosphorus, after colonising plant roots. In addition, they make plants more resistant to things like salinity, drought, and diseases.

- Ectomycorrhizal fungi: They establish symbiotic partnerships predominantly with trees (e.g., pine and oak), fulfilling a comparable function in nutrient absorption and stress resilience.

3. Endophytes:

Most endophytes are harmless microbes like bacteria and fungi that reside in plant tissues. Their ability to aid in plant growth, increase stress tolerance, and shield plants from diseases has been acknowledged. In many cases, the relationship between the plant and the endophyte is mutually beneficial.

Types of Endophytes:

Bacterial endophytes: They are represented by prevalent groups such as Azospirillum, Pseudomonas, Bacillus, and Burkholderia. They are recognised for enhancing the development of plants and facilitating the intake of nutrients.

Fungal endophytes: These group includes Fusarium, Trichoderma, and Penicillium, play a significant role in promoting plant wellness through processes that include improving resilience to stress and synthesising bioactive compounds.

4. Pathogenic interactions:

The term "pathogenic interaction" describes the negative dynamic that develops when disease-causing microbes (e.g., bacteria, fungus, viruses, or nematodes) form bonds with the plants that host them. Interactions like these mess with a plant's development, growth, and health in general. Plants are prone to mortality or decreased output when pathogens infiltrate their tissues, alter the biological processes of the host, and then drain nutrients.

Types of Pathogens:

Bacterial Pathogens: Examples includes Xanthomonas, Pseudomonas syringae, and

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Agrobacterium tumefaciens. These bacteria frequently infiltrate plants via natural apertures (stomata) or injuries, secreting poisons or enzymes that decompose plant tissues.

Fungal Pathogens: Common plant fungal infections include Phytophthora, Fusarium, Rhizoctonia, and Botrytis. They induce diseases such as blights, wilts, and rots by degrading cell walls in plants or interfering with natural plant processes.

Viral Pathogens: Plant viruses, like Tobacco Mosaic Virus (TMV) and Tomato Spotted Wilt Virus (TSWV), induce various symptoms such as mosaic patterns, restricted development, and fruit distortion. Viruses are frequently disseminated by insect vectors such as aphids or whiteflies.

5. **Plant Growth-Promoting Rhizobacteria (PGPR):**

Pseudomonas, Bacillus, and Azospirillum are PGPR examples that can colonise the rhizosphere and interact with plant roots to produce phytohormones (such as auxins and cytokinins), solubilise phosphate, and improve nutrient uptake. Plants can be primed to protect themselves against pathogen attacks by triggering ISR with PGPR. This enhances their immune response.

6. Phosphate-Solubilizing Microorganisms (PSM):

PSM enhances the availability of phosphorus by converting refractory forms of phosphorus in the soil into forms that are able to be absorbed by plants. Particularly in soils that are deficient in phosphorus, enhanced phosphorus absorption results in improved root development and overall plant growth. For example, Bacillus, Pseudomonas, and Penicillium.

7. Microbial Degradation of Organic Matter:

Nutrients like potassium, phosphorus, and nitrogen are released into the soil as microbes like saprophytic fungus and bacteria break down organic materials. Plants are able to absorb these nutrients, which boosts soil fertility and increases harvest yields.

Benefits of Utilizing Beneficial Microbes for Crop Growth:

1. **Enhanced Nutrient acquisition**: Nitrogen, phosphorus, and iron are three of the most important nutrients, and microbes make them more accessible and facilitate their absorption.

2. **Enhanced Stress Resilience**: Beneficial bacteria aid plants in withstanding abiotic challenges including drought, salt, and high temperatures, which improves their stress tolerance.

3. **Biological Control of Pathogens**: particular microbes safeguard plants against diseases by making antimicrobial substances, outcompeting detrimental species, or activating plant defence mechanisms.

4. **Diminished Requirement of Chemical Inputs:** By employing helpful bacteria, farmers can decrease their reliance on synthetic fertilisers and chemical pesticides, thereby reducing expenses and mitigating environmental damage.

5. **Augmented Crop Yields**: Plants that are healthier, better able to withstand stress, and protected from diseases tend to have larger yields.

6. **Sustainable Agriculture**: Microbes help improve soil health and lessen the environmental impact of farming, which

leads to more sustainable agricultural methods.

CONCLUSION:

An environmentally responsible and sustainable approach to boost crop growth, yields, and stress tolerance in agriculture is to use beneficial microorganisms. Long-term agricultural productivity can be enhanced, soil ecosystems can be supported, and there can be less dependency on chemical inputs by including microbial inoculants, biofertilizers, and biocontrol agents into farming operations.

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Ozone Washing of Fruits and Vegetables

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ABSTRACT

Post-harvest life of fruits and vegetables encounter microbes leading to diseases. Usually pesticides, fungicides and other inorganic chemicals are used to treat them. The consumer awareness towards the health effects of consuming those products cannot be neglected. Ozone washing of fruits and vegetables is one approach to deal with pathogenic microbes giving no harmful residues throughout the process. Ozone can kill the pathogenic microbes which promote the shelf-life and post-harvest quality.

INTRODUCTION

Fruits and vegetables are indispensable for a healthy and balanced diet. However, they have very short shelf-life which is associated with large number of foods borne illness that is connected with their consumption. With the aim of extending the shelf-life anti-microbial washing of fruits and vegetables is a routine post-harvest process. Chlorine, peracetic acid, electrolyzed water *etc.* are usually applied (Sarron *et. al*., 2021). The use of synthetic additives may be hazardous to food safety. Moreover, it may affect the health of consumers. Thermal processing can also be used to prevent pathogens (Prabha *et al.* 2015). However, this technology affects the quality of the produce.

Ozone is a powerful disinfecting agent that is Generally Regarded as Safe. In the European Union, ozone is used for treating water for food processing industry from early 1900 onwards. The use of ozone has been recognized by the regulatory agency in 2006 for wheat and flour industry (Legifrance List of Food Enzymes permitted in France). Ozone is also applied in water used for washing ready to use salad vegetables (ANSES). Ozone is effective in the inactivation of common microbes, pests, mycotoxins and pesticide residues. Ozone washing leads to less loss of product quality and ensures freshness. It is economically feasible and environmentally safe. Ozone is stable in air, but highly unstable and water, decomposing to oxygen: hence food products treated with ozone are free of pesticide residues.

Application methods of ozone in food industry

In post-harvest treatment ozone is applied in two forms: gaseous and liquid (Khawarizmi, 2018).

Ozone in air:

In this method the ozone is applied as fumigation. This is achieved by fixing an ozone generator in the storage room or container. A sensor is attached to determine the concentration of ozone in the container. Automatic switch can also be fixed for the ease of operation. In certain cases, a fan is fixed to assure the uniform spreading of the ozone (Ong et al., 2013). Ozone scrubber or potassium iodide is fixed on the exhaust for the safety of workers.

Ozone in water

In this method the ozone gas is applied to the water through a tube, which bubbles in the water. Ozone is water is more unstable. The water can be recycled after adding the gas (Khawarizmi, 2018).

Aquous ozone oxidized to oxygen in very short time. Aqueous ozone is more prone to dirt, organic matter, or soil which can reduce the oxidizing property. Aqueous ozone must be applied continuously to maintain the desired concentration.

Effect of ozone toward the fruits and vegetables after washing

Ozone is not proved with any carcinogenic effect toward humane health. Ozone is used in the treatment of drinking water. Ozone can remove the pesticide residues for the fruits and vegetables. Application of ozone can extend the shelf-life of fruits and vegetables. Ozone can remove pesticide residues, toxic organic compounds, and chemicals residues from the commodity.

While applying ozone to fruits and vegetables the desired concentration is very important. Too much and very low concentrations will have deleterious effect on the commodity.

They can extend the shelf-life of fruits and vegetables, and can reduce the microbial count on them. Ozone application maintains the quality of product after harvesting (Ali et al. 2018). Ozone can prevent the diseases caused by pythium. It also reduces the aging and weight loss of orange (Karaca, 2010). Ozone exposure can reduce the ethylene formation, thus controlling the ripening process. Ozone can reduce the foul smell and odor of vegetables and fruits.it can reduce the volatile components.

CONCLUSION

Despite all the good things ozone does, it can also be harmful. Concentration, time of exposure, sensitivity of the commodity towards ozone and cost are to be considered before the commercialization of this technology. Prolonged exposure of commodities to ozone can have deleterious effects on human health as well as commodity. Aromatic and volatile compounds may be lost or got inactivated during the process. Ozone on decomposition produces oxygen. So, oxygen sensitivity of the commodity should be determined before ozone application.

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Climate Change and Its Impact on Weed Growth and Control Strategies

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ABSTRACT

Climate change is rapidly altering the dynamics of agriculture, notably influencing weed growth and control strategies. Rising atmospheric carbon dioxide levels, increasing global temperatures, and changing precipitation patterns are reshaping weed ecology, leading to shifts in weed species distribution, accelerated growth and enhanced competition with crops. These changes pose significant challenges for farmers and agronomists, as conventional weed management practices may become less effective. Elevated CO_2 stimulates the growth of many weed species, particularly C_3 plants like *Chenopodium album* and *Ambrosia artemisiifolia*, which benefit from the CO_2 fertilization effect. Higher temperatures extend the growing season and enable heat-loving weeds such as *Amaranthus palmeri* and *Amaranthus tuberculatus* to proliferate and invade new regions. Additionally, altered precipitation patterns favour drought-tolerant and water-loving weeds, further complicating control efforts. Climate change also impacts the efficacy of herbicides, as environmental stressors like heat and drought reduce the uptake and effectiveness of common herbicides, including glyphosate and 2,4-D. This, combined with the growing problem of herbicide-resistant weeds, underscores the need for integrated weed management strategies. Mechanical and cultural control methods, such as tillage and cover cropping, are also affected by erratic weather patterns, making timely and effective weed control more difficult. To address these challenges, the adoption of diversified weed

management strategies is essential. Integrated approaches that combine chemical, mechanical, biological, and cultural methods offer the best chance of adapting to the evolving weed pressures driven by climate change. Additionally, advancements in precision agriculture and the development of climate-resilient crops provide promising avenues for sustainable weed management in a changing environment.

INTRODUCTION

Climate change has become a defining global issue, influencing various facets of agriculture, including the growth and management of weeds. As atmospheric carbon dioxide (CO_2) levels rise, global temperatures increase, and weather patterns become more erratic, the ecological dynamics of weeds shift, directly affecting their proliferation, distribution, and resistance to control methods. These changes pose significant challenges to farmers and agronomists seeking effective weed management strategies. This article explores how climate change impacts weed growth and control strategies, examining shifts in weed species, altered herbicide efficacy and the necessary adjustments in weed management practices.

1. Impact of Climate Change on Weed Growth

1.1 Increased CO_2 Levels and Weed Growth

One of the most immediate effects of climate change is the rise in atmospheric CO_2 levels, which alters plant growth patterns. Elevated CO_2 can stimulate photosynthesis in many plant species, including both crops and weeds, through the CO_2 fertilization effect. This phenomenon can lead to faster growth rates and larger biomass for certain weed species, potentially outcompeting crops for essential resources like water, nutrients, and light. Studies have shown that C_3 plants, such as *Chenopodium album* and ragweed *Ambrosia artemisiifolia*, which utilize the C_3 photosynthetic pathway, respond more positively to elevated CO_2 levels compared to C_4 plants such as barnyard grass *Echinochloa crus-galli* and crabgrass *Digitaria* spp.. The enhanced growth of C_3 weeds, combined with a prolonged growing season due to warmer temperatures, can lead to increased weed competition with crops.

1.2 Temperature and Weed Growth

Rising global temperatures have a direct impact on the phenology (life cycle events) of weed species. Warmer conditions can extend the growing season in many regions, leading to earlier germination, faster growth and potentially more generations of weeds per year. Weeds that thrive in warmer climates, such as *Amaranthus palmeri* and *Amaranthus tuberculatus* are likely to expand their range northward or into cooler regions where they previously were not a significant problem. Additionally, higher temperatures can increase the competitive ability of certain invasive weed species, making them more aggressive in environments where they were once suppressed by cooler climates. For instance, *Cirsium arvense* and *Kochia scoparia*, both significant agricultural weeds, have been observed to proliferate more effectively under warming conditions, particularly in areas with longer growing seasons and reduced frost risk.

1.3 Changes in Precipitation Patterns

In addition to temperature and CO_2, changing precipitation patterns due to climate change also influence weed growth. In regions where rainfall becomes more erratic or where droughts are more frequent, drought-tolerant weed species such as *Setaria* spp. and *Salsola tragus* are expected to become more dominant. Conversely, in regions experiencing increased rainfall, water-loving weeds like *Cyperus* spp. and *Centaurea solstitialis* may proliferate. The variability in precipitation can also affect the timing of weed emergence, altering the synchronization between crop planting and weed control efforts. This variability makes it more challenging for farmers to implement effective pre-emergence herbicide applications or mechanical weed control measures, potentially leading to higher weed pressure during critical crop growth stages.

2. Impact of Climate Change on Weed Control Strategies

2.1 Herbicide Efficacy and Resistance

Climate change not only affects weed growth but also influences the effectiveness of herbicides. Herbicide efficacy is highly dependent on environmental conditions such as temperature, humidity, and rainfall. Rising temperatures and altered precipitation patterns can reduce the effectiveness of certain herbicides, making weed control more difficult. For example, glyphosate, one of the most widely used herbicides globally, has been shown to be less effective under drought stress conditions. Similarly, herbicides such as 2,4-D and dicamba are less effective when temperatures are too high, as plants under heat stress may close their stomata, reducing herbicide uptake. Furthermore, climate change can exacerbate the issue of herbicide resistance. Weeds that thrive under changing environmental conditions, such as *Conyza canadensis* and *Ambrosia trifida*, have already developed resistance to multiple herbicide modes of action, including glyphosate and ALS inhibitors. As these weeds expand their range and reproduce more rapidly under favourable climate conditions, the selection pressure for herbicide resistance may increase. This trend poses a significant threat to conventional weed management strategies that rely heavily on chemical control.

2.2 Mechanical and Cultural Control Strategies

Mechanical and cultural control methods, such as tillage, mulching, crop rotation, and cover cropping, are important components of integrated weed management. However, climate change is affecting the effectiveness and feasibility of these methods. For example, prolonged periods of drought or increased rainfall may limit the ability of farmers to implement timely tillage or cultivation practices, which can lead to higher weed pressure. Cover cropping, an effective strategy for suppressing weeds through competition and allelopathy, may also be impacted by climate change. While cover crops like rye (*Secale cereale*) and hairy vetch (*Vicia villosa*) have been shown to reduce weed biomass, the success of cover cropping depends on adequate moisture and favourable temperatures for growth. In regions experiencing more frequent droughts or erratic weather patterns, the ability of cover crops to establish and compete with weeds may be diminished.

Additionally, changes in weed species composition due to climate change may require adjustments in crop rotations. Crops that were previously effective at suppressing certain weed species may no longer provide the same level of control as new or more aggressive weeds emerge in response to shifting climate conditions.

2.3 Biological Control Methods

Biological control, which involves the use of natural predators, pathogens, or other organisms to suppress weed populations, is another weed management strategy affected by climate change. The efficacy of biological control agents is often closely tied to environmental conditions. For instance, fungal pathogens used to control weeds, such as *Alternaria alternata* for controlling *Abutilon theophrasti*, may be less effective under higher temperatures and lower humidity. Furthermore, the range and activity of weed biocontrol agents, such as insect predators, may shift with changing climate conditions. This shift could either enhance or limit the effectiveness of biological weed control, depending on how climate change affects both the weed and the biocontrol agent.

3. Adapting Weed Management to Climate Change

Given the wide-ranging impacts of climate change on weed growth and control strategies, adapting weed management practices is essential for sustainable agricultural production. A holistic approach, including diversified weed management strategies, must be employed to mitigate the risks associated with climate change.

3.1 Integrated Weed Management (IWM)

IWM combines multiple control strategies, including chemical, mechanical, cultural, and biological methods, to manage weeds in a sustainable manner. In the context of climate change, IWM becomes even more critical as a flexible and adaptive approach to weed control. The integration of herbicide rotation, cover cropping, crop rotation, and mechanical control methods can help reduce the reliance on a single control strategy, mitigating the risks of herbicide resistance and weed proliferation under changing climate conditions.

3.2 Climate-Resilient Weed Control Technologies

Advancements in precision agriculture, such as the use of drones, sensors, and data analytics, offer promising solutions for adapting weed management to climate change. Precision technologies can allow farmers to monitor weed populations more accurately and apply herbicides or mechanical controls in a targeted and efficient manner, reducing the overall input costs and environmental impact. Additionally, breeding crop varieties that are more competitive with weeds under stress conditions, such as drought-tolerant or heat-resistant crops, can help farmers manage weeds more effectively in a changing climate.

CONCLUSION

Climate change is profoundly affecting weed growth and control strategies, with elevated CO_2 levels, rising temperatures and changing precipitation patterns creating new challenges for weed management. Weeds are becoming more aggressive, expanding their range, and developing resistance to herbicides, making it increasingly difficult to control them using conventional methods. Adapting weed management strategies to climate change requires a holistic, integrated approach that combines chemical, mechanical, cultural and biological methods. By employing IWM strategies and leveraging climate-resilient technologies, farmers can mitigate the impacts of climate change on weed control and maintain sustainable agricultural productivity in the face of a changing environment.

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From Plague to Prevention: The Battle against Desert Locust

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ABSTRACT

Locust is a pest well known for eradicating stretches of natural vegetation as well as acres of farm cultivated crops. These short horned grasshoppers thrive well in their solitary phase and cause havoc to farmers in their gregarious phase. Out of four species present in India, the desert locust is the most dangerous of all as both its hopper and adult stages damage the crops particularly during July to October. Prevention, identification, amalgamation of cultural, chemical and mechanical methods such as digging trenches, beating drums, using chemicals like Malathion, Fenvalerate etc. can control and help in management of the pest.

INTRODUCTION

Locusts are the short-horned grasshoppers, belonging to order Orthoptera and family Acrididae. with highly migratory nature. They can form swarms (adult's congregation) and hopper bands (nymph congregation). Various favorable environmental conditions increase their number, growth, migration and spreading across multiple countries, which make this a pest of great importance. This group of insects can contain hundreds of pest species which cause tremendous decline in food production and also affect rural as well urban populations. Locust shows high impact on natural, cultivated crops and vegetation and can cause national emergency of food and fodder (CABI, 2020; Pandey *et al*., 2021). In India, four species of locust are found:

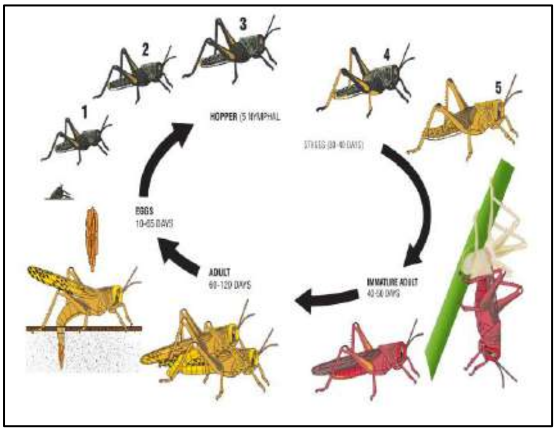
1. Desert locust (*Schistocerc agregaria*)
2. Migratory locust (*Locustami gratoria*)
3. Bombay locust (*Nomadacrissuccinata*)
4. Tree locust (*Anacridium sp.*)

Behavior of locust

Locust behavior depend on density of their population. High density of locust cause plagues and a variation in colour, size and behavior is observed at a lower density. Locusts are generally cryptic and solitarious in nature, grey in colour and avoid the contact with other mates. But prior to the formation of marching bands, all the solitarious locusts start to congregate at night and increase the local population, where they change their colour (black to pink), shape, behavior and become mature due to potent stimulus. After maturity, their colour changes from pink to yellow and they start to fly in bands and destruct everything that come in their way. Locusts exhibited two phases which are phenotypically different: solitary and gregarious. Rapid and swift behavioral transitions and shooting local population start a phase of pest outbreak. Desert locust preferably feed on leaves, flowers and bark of hundreds of plant species. They can consume approximately 35,000 people's food per day (CABI, 2020).

Life cycle of desert locust

The locusts complete their life cycle in three stages-



1. **Egg stage-** While mating, the male clings on female back and copulation lasts for 8-24 hours. Egg laying starts soon after the mating in February and hatches in month of March. The female prefers sandy moist soil for egg laying. A single female can lay up to 11 egg-pods, 5-10 cm deep and each pod containing up to 120 eggs. Female protect the eggs with frothy secretion. Eggs are curved, 7-9 mm, resembling the grain of rice (Atwal and Dhaliwal, 2008).

2. **Hopper stage-** Eggs hatch into hoppers about 2 weeks after being laid. Newly emerged hoppers are light yellow but quickly they turn into black colour (gregarious phase). Gregarious hoppers grow in 5 nymphal stages and duration lasts 6-8 weeks in spring and 3-4 weeks in summer. Young adults are pink in colour and this stage is also known as fledgling.

3. **Adult stage-** Fledgling change into immature adults in about 10 days. With the onset of adaptive environmental conditions, within 3-4 weeks, immature adults transformed into mature ones (CABI, 2020).

Breeding and distribution of desert locust

Desert locusts covered 64 countries of Central Region, Eastern region and Western region (Sharma, 2014).

Sl. No.	Season	Month	Area
1.	Winter	November-December	Red sea and Gulf of Aden, coast of Arabia, Coast of Iran and Pakistan
2.	Spring	January-June	Western Sahara, Mauritania, Libya, Sudan, Afghanistan, Central, Eastern Arabia
3.	Summer	July-October	Ethiopia, South Arabia, Mekran, Tharparker and Cholistan desert of Pakistan, Thar desert of Rajasthan, Gujarat, Haryana in West India

Management of desert locust

1. Beating of adults to kill them with thorny sticks, brooms and then burry
2. Use of fire throwers and fire torches
3. Shaking of bushes at night and then burry or burnt them
4. Beating of drums and waving of white piece of cloth to prevent locust settling on crops
5. Digging of trenches in front of marching hoppers dusted with Lindane
6. Protect the birds which feed on locust like myna and tiliar
7. Use of poison baits
8. Dusting with insecticides like Malathion 5% DP, Quinalphos 1.5% DP, Fenitrothion 0.4% DP, Fenvalerate 96% ULV
9. Damage hot spots of locusts before the outbreak
10. Regular monitoring and survey
11. Blanket sprays of insecticides to control hopper bands
12. Aerial spraying of ULV formulation of insecticide with ULV nozzles on helicopter and drone
13. Ploughing of field to expose eggs to destroy in sunlight
14. Training farmers to identify, locate and use of latest technologies
15. Identification and monitoring of locust with RAMSES, SPOT and SMOS.
16. Following instructions and warnings provided by Locust Warning Organization, Jodhpur, Rajasthan and planning the prevention and management as per the instructions given by such type of organizations (FAO, 2001a; CABI, 2020).

CONCLUSION

Preventive measures and pre-planning of tackling the locust attack can save crop failures. Hence, following guidelines of LWO, and other farmer-help government organization along with a mix of cultural, mechanical, chemical methods is a solution to the problem. New technological advances and guidelines should be a part of the trainings provided by agricultural organizations to update the farmer regarding advances so as to ensure prevention and proper management.

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Plant–Mediated Nanoparticles: A Ray of Hope for Cancer

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ABSTRACT

The article discusses the potential of plant-mediated nanoparticles, specifically copper nanoparticles (CuNPs), in cancer treatment. It highlights the increasing cancer rates in India and the limitations of traditional treatments like chemotherapy, which often fail to stop tumor growth and recurrence. The study focuses on ***Hippophae rhamnoides* L.**, a plant used in India and Tibet for medicinal purposes, as a source for synthesizing CuNPs. Using a "green synthesis" approach, which is environmentally friendly and cost-effective, the copper nanoparticles are created through the interaction of plant extracts and copper ions. These nanoparticles are then characterized using techniques like UV-Vis spectroscopy and X-ray diffraction. The synthesized CuNPs can be tested for anticancer activity, particularly against the HeLa cervical cancer cell line, using assays such as MTT to assess cell metabolic activity. The green synthesis method offers advantages over chemical synthesis, including minimal use of toxic chemicals and eco-friendliness. CuNPs, due to their unique properties at the nanoscale, have promising applications in modern medicine, including biological imaging, drug delivery, and cancer therapy. The study suggests that CuNPs from ***Hippophae rhamnoides*** could serve as a sustainable and effective cancer treatment, potentially opening new avenues for human-friendly, plant-based medicines.

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INTRODUCTION

In India, cancer is currently the main reason for too much medical costs, unstable finances, and going up costs before death (Kulothungan V *et al.*, 2022). Men had higher rates of lung cancer, mouth cancer, stomach cancer and nasopharyngeal cancer according to population-based cancer registries. **Cancer** is when cells grow in your body in uncontrolled manner and make you sick. Cancer happens when some cells in your body start to grow out of control. Normally, cells grow, divide, and die in a controlled way. But when cancer starts, cells keep dividing and don't die when they should. This can form a mass of tissue called a tumour. These abnormal cells can also spread to other parts of the body. In the **medical Industry**, the cancer most **common method** is **chemotherapy.**

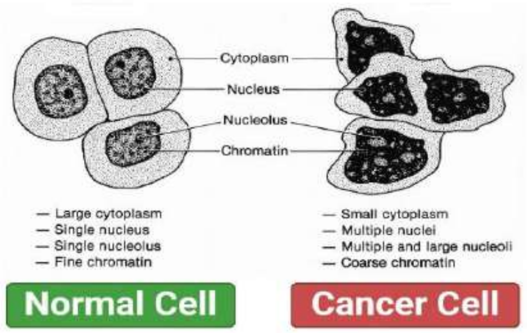

Fig.1: Morphology of Cancer cell (Baba AI *et al.*, 2007)

Chemotherapy is frequently used in clinics because of its simple and useful approach. Radiation and surgery are two more common in Chemotherapy. But chemotherapy is unsuccessful at stopping tumor growth, spread, and repeated occurrence of tumor (Adjiri A 2022). The treatment of cancer experiences various complications such as pain, tiredness, feeling sick, and diarrhoea. Also use anticancer drugs such as taxanes, vinca alkaloids, angiogenesis inhibitors, platinum-based therapies, and proteasome inhibitors (Loprinzi *et al.*,2020).

Many plants have ethnomedicinal applications in different countries around the world, for instance in Tibet seed, fruit, and leaves are used for edema, tissue generation, skin grafts, burning injury and cosmeceutical. While India its fruit is used as a digestive agent (Andualem *et al.*, 2020, Lee *et al.*,2021, Pundir *et al.*, 2021) People are hunting the path to synthesize CuNPs from plants and exploring them for anticancer activity. The plant *Hipphophae rhamnoides* is currently present in **India** located at **ranjrik**, **Lahul-spiti, himachal Pradesh** (GU *et al.*, 2023).

Fig.2: *Hippophae rhamnoides* L. (Żuchowski J. *et al.* 2023)

In recent years scientists have synthesized the copper nanoparticles by using the ***Hippophae rhamnoides*** L plant. To synthesize the copper nanoparticle a green approach can be used. One of the objectives was to impart the medicinal values of the plants in the copper nanoparticles. Laboratory synthesized copper nanoparticles are being characterized using a complex instrument like UV vis spectroscopy (UV-Vis), and X-ray diffraction (XRD). Well-characterized plant-mediated copper nanoparticles (CuNPs) can be used to check the in-vitro anticancer activity against the

Hela (cervical cancer cell line) cell line by MTT (a colorimetric assay for assessing cell metabolic activity) assay (Chandraker *et al*. 2020).

Green synthesis in plants

Green synthesis is a developing area in the field of biotechnology and provides economic and environmental benefits as an alternative to chemical and physical methods. Green synthesis is an eco-friendly and cost-effective method for producing nanoparticles. In this method, nontoxic reagents which are eco-freindly and safe at the biological level is used. Various natural resources are available in nature such as plant extract, cyclodextrin and many more use for the synthesis of plant. The plant-mediated green synthesis of nanoparticle is beneficial for the environment there is a minimal use of hazardous and toxic chemicals (Asanda Mtibe ,2018)**.**

Nanoparticles are tiny particles ranging from 1 to 100 nm in size. Materials that exhibit unique physical and chemical properties due to their small size. Nanomaterials are also known as "zero-dimensional". Nanotechnology is a known field of research since the late 20th century, with Nobel laureate Richard P. Feynman being a beginner in the field. Nanoparticles can be in a various shapes and dimensions, from 0D to 3D. Their properties, such as optical characteristics are influenced by their size. Nanoparticles are tiny particles with dimensions in the nanometre range measuring one-millionth of a meter (Li *et al*., 2023).

Nanoparticles in modern medicine: State of the art and future challenges

Nanoparticles can provide significant improvements in modern biological imaging of cells and tissues using florescence microscopy as well as in modern magnetic resonance imaging (MRI) of various regions of the body. Nanoparticles are also used in Optical imaging, AIDS/HIV therapy, and also used in a Drug and gene therapy which is a cancer therapy.

Synthesis of copper nanoparticles of *Hipphophae rhamnoides*

For the synthesis of these nanoparticles top to down approach is used, in this method *Hipphophae rhamnoides* L. plant extract is prepared and then for the synthesis of nanoparticles the Cu^{+2} ions source is added, which creates nanoparticles in a colloidal solution, this solution is centrifuged and CuO nanoparticles are ready, which can be characterized by several methods.

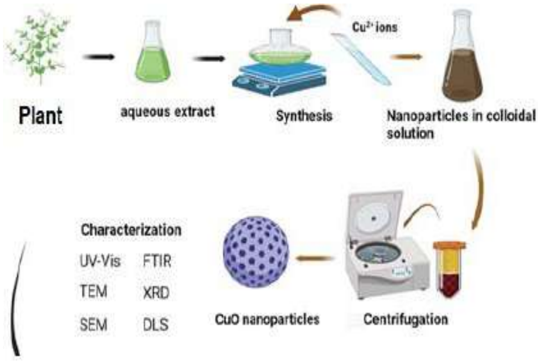

Fig.3: Diagrammatic representation of CuNPs synthesis process (Nzilu Dennis *et. al*. 2023)

The study performed by Loo *et.al*. 2012 aimed to develop CuNPs using *Hippophae rhamnoides* L., the pale-yellow color turned into dark brown color. This suggests the formation of CuNPs from the stem extracts of *H. rhamnoides*. The dark color was observed due to the reduction of copper (III) to cupric ion (Cu+). It happened due to the interaction between photons and conduction. Different methods also available for different modification check such as, Functional group identification by FTIR analysis, Phase identification of the synthesized CuNPs by XRD, Morphological analysis of the synthesized CuNPs by SEM, HPLC for identification biological compounds with CuNPs.

CuNPs exhibit cytotoxicity because they interact with functional groups of proteins and with nitrogen bases and phosphate groups present in DNA within the cell (Din *et al*., 2017). In **conclusion**, CuNPs synthesized from *H. rhamnoides* L. stem could be effective as an anticancer agent, the effect of different concentrations of CuNPs against HeLa (cervical cancer cell line). Which can open doors to the sustainable and human-friendly medicine in the health sector.

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Carbon Crisis: Addressing Greenhouse Gas Emissions for a Greener Planet

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ABSTRACT

Emissions of greenhouse gases (GHGs) form a significant reason for climate change primarily due to human activities such as energy production, transportation, agriculture, and industrial processes. The most important GHGs include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are known for trapping heat in the Earth's atmosphere, causing global warming. The Kyoto Protocol also deals with the reduction of these gases causing global warming by controlling their GWP. Among the many GHSs, one of the most common ones is CO_2. However, due to their popularity, it could be perceived as if it's the only GHG, though methane and nitrous oxide have much higher GWP(Global Warming potential). Methane and nitrous oxide emissions are normally associated with several sectors like transportation, and agriculture, from the combustion of fossil fuel and fertilizers, respectively. Adaptation measures entail a transition to the use of renewable energy, efficient use of energy, and proper production in agriculture through climate-friendly agriculture-regenerative and precision agriculture. Carbon capture and storage technology can also be part of a set of new technologies that are promising, with electric vehicles showing a similar profile in terms of their potential to ease sectors.

INTRODUCTION

Greenhouse gases (GHGs) absorb and reemit heat, making the atmospheric belt warm. Important GHGs include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone. While these exist naturally, human activities like burning fossil fuels, energy production, transportation, agriculture, and industrial processes are increasing GHG levels which in turn cause global warming, a significant reason for climate change. Carbon dioxide (CO_2) and other greenhouse gases act like a blanket, grasping Infrared radiation and not allowing it to exit into outer space.

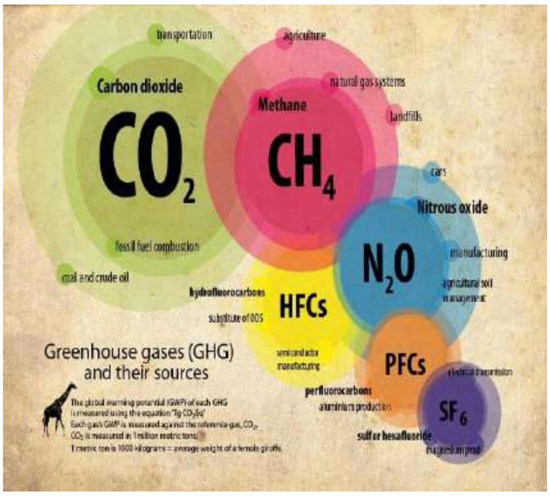
More importantly, different types of greenhouse gases stay in the atmosphere for differing periods and absorb differing amounts of heat. The "global warming potential" (GWP) measures how much warming a gas cause over a certain period, which is often 100 years (Table 1).

Table 1: Kyoto Gases (IPCC 2007)

Greenhouse Gas	Global warming potential (GWP)
1. CO_2 (Carbon dioxide)	01
2. CH_4 (Methane)	25
3. Nitrous oxide (N_2O)	298
4.Hydrofluorocarbons (HFCs)	124-14,800
5.Perfluorocarbons (PFCs)	7,390-12,200
6. Sulphur hexafluoride (SF_6)	22,800
7. Nitrogen trifluoride (NF_3)[3]	17,200

Major Sources of Greenhouse Gas Emissions

1. **Energy Production:** Electricity and heat are generated from fossil fuels, among the main sources of greenhouse gas emissions, mainly CO_2. Fossil fuel, such as coal, oil, and natural gas, combusts to supply energy in power plants for industrial uses.



2. **Transportation:** The bulk of CO_2 and other greenhouse gases is emitted by vehicles run on gasoline and diesel fuels. Upon combustion, gasoline or diesel fuels release CO_2 as exhaust, trapping heat, thus warming the planet. This is further accelerated because of the massive number of vehicles owned in the world.

3. **Agriculture:** Major GHG-emitting sources include methane from livestock raised for agriculture purposes and nitrous oxide from fertilizers. Livestock Methane Emissions is produced by enteric fermentation in livestock, mainly ruminants (cattle, sheep, and goats). Furthermore, Synthetic fertilizers and organic manures used in agriculture lead to the emission of nitrous oxide. It is a highly potent greenhouse gas, with a global warming potential of about 298 that of CO_2 over 100 years.

4. **Industrial Processes:** Among the giant producers of the greenhouse gas that causes climate change in the world, manufacturing and chemical production top the list. These sectors have already produced several gases through their processes, including carbon dioxide and

fluorinated gases, which vary with differences in environmental degradation.

5. **Waste Management**: Landfills and waste treatment plants are leading emission sources of methane (CH_4), a potent greenhouse gas. Organic wastes like food, paper, and yard waste are buried in landfills to decompose over time. This decomposition results in anaerobic conditions, which increase the production of methane.

What Can We Do?

1. **Energy Conservation:** Working your way in reducing carbon footprints is by helping in conserving energy at home. Here's how we can do it effectively:

- **Insulation**: Improve the insulation of your home to keep it warm or cool with less energy use. Adequate insulations in ceilings, roofs, and walls allow reduction in heating and cooling costs.

- **Energy-Efficient Appliances**: replace old appliances with energy efficient or less-electric ones. Energy STAR-labelled appliances have more efficiency and consume minimal amounts of energy.

- **Green Energy**: switch to renewable energy for electricity supply. Many utility companies now have options for green energy plans, or can even install solar panels on your property and generate your own clean energy.

2. **Transportation Choices**: Our mode of transportation is the biggest choice for difference in carbon footprint. Consider these alternatives:

- **Using public transit**: Using public transport reduces the number of vehicles lowering overall emissions and also prevents traffic congestion.

- **Biking / Walking:** A short journey can be covered by biking/walking, which is environmentally friendly and also good exercise for your body.

- **An electric vehicle**: is a low-carbon alternative to a traditional gas-guzzling or diesel-burning car. There are no tailpipe pollutants and it can be powered using renewable energy sources.

3. **Changes in Lifestyle**: Changes in lifestyle can also reduce the greenhouse gas emissions:

- **Reduce Meat**: Reduce the amount of meat and increase the intake of plant products with the aim of reducing methane emissions associated with livestock.

- **Recycling**: Recycling paper, plastic, and metal in the right manner reduces the extraction of fresh stuff and minimizes emission from waste processing.

- **Reduce Waste:** Activities such as reusable shopping bags, containers, bottles, and composting organic wastes reduce methane emissions from landfills.

- **Reuse:** We should reuse the materials, and not waste them. The biodegradable materials can be reused as organic manure for agricultural and horticultural fields, while the non-biodegradable wastes can be recycled.

CONCLUSION

Addressing GHG emissions requires a multi-pronged approach to renewable energy, sustainable agriculture, and technological innovations of electric vehicles and carbon capture to name a few. There is scope for

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individual, industrial, and governmental action to mitigate change and provide for sustainability to be reached globally. Comprehensive policy across all sectors toward a clean-energy low-carbon future is an important requirement.

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Food Security –Pesticides Residues in Food

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ABSTRACT

Food security, a critical aspect of global health and nutrition, is increasingly challenged by the presence of pesticide residues in food products. Pesticides are widely used in agriculture to enhance crop yields and control pests, but their residues can pose significant risks to human health and the environment. This abstract explores the intersection of food security and pesticide residues, highlighting the impact of pesticide use on food safety and availability. It examines the regulatory frameworks and safety standards established to manage pesticide residues and assesses their effectiveness in protecting public health. Additionally, it discusses the implications of pesticide residues on food security, including potential health risks, economic costs, and the sustainability of agricultural practices. The abstract concludes with a call for integrated strategies that balance the need for effective pest control with the imperative to safeguard food quality and ensure long-term food security.

INTRODUCTION

In today's world, the need for food security and the safety of our food supply are more pressing than ever. With a growing global population, ensuring a steady, reliable food supply is a top most priority. For hastlefree food supply throughout the year we have to enhance the production of food commodity and for crop protection pesticides are very much important to mitigate the pests and to reduce the crop damage. Here's a look at how we can navigate this intersection and make informed choices for ourselves and our families. According to the World Food Summit of 1996, food security can be achieved when all the people have physical and financial access to enough safe, nutrient-dense food that satisfies their dietary demand for an active and healthy life, regardless of their circumstances. The idea of food and nutrition security (FNS) was developed through a number of discussions. and covered a wide range of topics, including the environment, economy, health, and food access. It is also very closely connected to the fulfillment of the human right to food and nutrition (HRFN), even though this right is separate from the idea of FNS (Albuquerque, 2009).

Dimensions of food security

a) **Food availability**: This refers to the "supply side" of the food security and is based on net trade, stock levels, and the quantity of food produced.

b) **Economic and physical access to food**: In household level food security is not ensured by a sufficient supply of food at the national or international level. In order to achieve food security goals, policymakers are now focusing more on incomes, expenses, markets, and prices due to worries about inadequate food access.

c) **Food utilization**: Generally speaking, utilization refers to how the body uses the many nutrients found in food to its fullest potential. Individuals that receive proper care and feeding will consume enough energy and nutrients as a result of food preparation, a varied diet, and intra-household food distribution. When combined with optimal biological utilization of ingested food, this establishes an individual's nutritional status.

d) **Consistency of the remaining three dimensions throughout time**: Even if you eat enough food now, you can be still classified as food insecure if you occasionally lack access to enough food, which could lead to a decline in your nutritional status. Your level of food security may be impacted by unfavorable weather, unstable political environments, or economic issues (such as increased food prices and unemployment).

Pesticides: The Double-Edged Sword

In today's agriculture, pesticides are indispensable instruments. They preserve crops from being lost, which keeps food costs steady and supply abundant. But there is a drawback. Health concerns have been highlighted by pesticide residues, which are minuscule amounts of chemicals that may linger on or in food after application. Exposure to specific pesticides for long time may result in possible health hazards, such as cancer, hormone abnormalities as well as different abnormalities.

Role of pesticides

1. Enhancing Crop Yields

- **Increased Productivity:** In order to prevent pests, illnesses, and weeds from seriously reducing agricultural yields, pesticides are essential. For example, fungicides fight plant diseases brought on by fungi, while insecticides target dangerous insects that feed on crops. Pesticides assist farmers in getting greater yields from the same amount of land by minimizing crop damage.

- **Economic Benefits:** Farmers benefit from higher crop yields because they boost their profitability. Pesticides help

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create more consistent and predictable harvests by reducing losses from pests and diseases. This helps stabilize food prices and support economic stability in the agricultural sectors.

2. Reducing Food Waste

- **Preventing Losses:** By safeguarding crops during development and storage, pesticides contribute to a decrease in food waste. Large amounts of produce could be lost to pests or spoiling in the absence of pesticides. For instance, pesticide-treated stored grains are less likely to become infested by insects, thus presereve the quantity and quality of the food.

- **Preserving Resources:** Pesticides help ensure that labor, water, and land are used efficiently by lowering the quantity of food lost.

3. Addressing Global Challenges

- **Feeding a Growing Population:** The need for food will only increase as the world's population is expected to reach 9 billion people by the year 2050. Due to their ability to increase agricultural yields and lower losses, pesticides are essential in supplying this demand. They assist farmers in maximizing the use of available land while producing enough food to satisfy a growing population.

- **Adapting to Climate Change:** Crop pressure from pests and diseases may increase as a result of climate change. By preventing the spread of diseases and new pests that flourish in climate change, pesticides can help alleviate some of these problems. Maintaining agricultural output in a changing environment requires this adaptation.

4. Ensuring Food Safety

- **Controlling Harmful Pests:** Some pests, like rats and locusts, can seriously harm crops and even result in a food shortage. By assisting in the pests' control, pesticides contribute to the stability and dependability of food supply. This is particularly important in regions where pest outbreaks could jeopardize the security of food supplies.

- **Protecting Public Health:** Pesticides not only save crops but also contribute to public health by preventing the spread of illness. For example, controlling mosquito populations with pesticides helps lower the prevalence of diseases like dengue fever and malaria.

5. Supporting Sustainable Agriculture

Integrated Pest Management (IPM): A part of integrated pest management, which integrates chemical, biological, cultural, and physical techniques, is the use of pesticides. By using fewer chemical pesticides and lowering their potential impact integrated pest management (IPM) seeks to manage pests in a way that is both economically and environmentally sustainable.

6. The Controversy and Future Outlook

Despite their advantages, the use of pesticides is not without controversy. Concerns over potential negative effects on human health and the environment have led to calls for a reduction in the use of pesticides and an increase in the use of alternative pest management strategies. Finding solutions that protect the environment and human health requires striking a balance between these concerns and the benefits of utilizing pesticides.

➢ **Regulations and Safety Standards for Pesticide Residues:** Ensuring Safe Food Supply

The use of pesticides in agriculture today is essential for crop protection and excellent yields. However, strict laws and safety requirements have been implemented as a result of worries about possible health risks from pesticide residues. This is a thorough explanation of the laws and regulations governing pesticide residues in order to protect public health.

1. Setting Maximum Residue Limits (MRLs)

Maximum Residue Limits, or MRLs, are the highest levels of pesticide residues that are legally allowed on food products. They are there to ensure that any residues are at levels considered safe for human consumption.

Establishing MRLs:

- **Scientific Research:** MRLs (Maximum Residue Limit) are established by means of comprehensive scientific investigation. To determine acceptable levels, toxicologists and agronomists assess pesticide toxicity data, metabolism, and residue behavior.
- **Risk Assessments:** These evaluations take into account both acute and chronic exposure to pesticide residues as potential dangers. To protect vulnerable groups, other factors such as age, health status, and dietary habits are also taken into account.

Regulatory Bodies:

- **United States:** In compliance with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Food, Drug, and Cosmetic Act (FDCA), the Environmental Protection Agency (EPA) sets maximum residue levels (MRLs) for pesticides used in the United States.
- **European Union:** The European Food Safety Authority (EFSA) in the EU sets MRLs, and Regulation (EC) No 396/2005 is the legal framework that governs compliance.
- **International:** The Codex Alimentarius Commission, established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) to ensure global food safety and promote trade, sets international maximum residue levels.

2. Monitoring and Enforcement

Testing for Residues:

- **Routine Testing:** Governments and regulatory agencies regularly check food products to make sure they adhere to MRLs. This testing is done by government laboratories as well as independent organizations.
- **Sampling:** Samples of food products are collected from farms, processing plants, and retail establishments, among other locations throughout the supply chain. This makes sure that at every stage of the food manufacturing process, pesticide residue levels are kept within safe bounds.

Enforcement Actions:

- **Compliance Monitoring:** Regulatory bodies use testing and inspections to keep an eye on whether established MRLs are being followed. Products that don't comply may be taken off the market, and manufacturers risk fines.
- **Public Health Alerts:** Public health alerts may be released to notify the public and encourage corrective action if serious problems are found. This guarantees openness and prompt handling of any hazards.

3. Risk Assessment and Management

Risk Assessment Process:

- **Exposure Assessment:** Based on dietary habits and residue levels, estimates the amount of pesticide residues in food items to which consumers are likely exposed.
- **Toxicity Assessment:** examines the possible health impacts of pesticide residues using epidemiological studies and laboratory research data.
- **Risk Characterization:** combines toxicity and exposure evaluations to calculate the total risk to human health and define safe thresholds

Risk Management Strategies:

- **Labeling Requirements:** Labels for pesticides provide usage guidelines as well as safety measures to reduce hazards. Pre-harvest intervals—a period of time during which a pesticide cannot be administered in order to guarantee residue levels are below maximum residual levels—are another detail included on labels.
- **Good Agricultural Practices (GAPs):** Promote pesticide-use reduction and residue-reducing practices, such as appropriate timing, application methods, and integrated pest management (IPM) strategies.

4. Consumer Protection and Education

Transparency and Information:

- **Educational Resources:** Resources are made available by regulatory bodies and groups to inform the public on safe food handling procedures, pesticide residues, and the advantages of pesticide laws.
- **Food Labels:** Information about whether produce is cultivated organically or conventionally is frequently included on labels. Organic produce may still include natural or non-synthetic pesticides, even though it usually has lower amounts of synthetic pesticide residues.

Consumer Choices:

- **Washing and Peeling:** To reduce the amount of pesticide residue in their food, customers can wash and peel fruits and vegetables as needed. These processes help to eliminate surface residues and reduce overall exposure.
- **Organic Options:** Customers worried about pesticide residues have an option because organic fruit is grown with less pesticide used. However, natural or non-synthetic pesticides may still be used in organic farming.

5. Ongoing Challenges and Future Directions

Emerging Contaminants:

- **New Pesticides:** Regulatory bodies constantly evaluate the safety of newly manufactured and applied pesticides and set maximum residue levels (MRLs). To assess the potential dangers of new pollutants, more study is needed.
- **Global Trade:** International trade can complicate residue control since various countries may have varying MRLs. The Codex Alimentarius Commission seeks to harmonize MRLs to ensure consumer safety and to advance global trade.

Technological Advances:

- **Improved Testing Methods:** Pesticide residues at lower levels can now be more precisely detected because to developments in analytical technologies. This improves the capacity to keep an eye on compliance and guarantee food safety.

- **Sustainable Practices:** Reducing dependency on synthetic pesticides and minimizing residue concerns are the goals of research into sustainable agriculture practices and alternative pest management techniques.

➢ **Consumer Actions: Reducing Exposure**

Although laws are in place to guarantee the safety of food, people should take additional precautions to reduce their exposure to pesticide residues:

1. Wash and Peel:

- **Washing:** Certain pesticide residues may be removed from fruits and vegetables by giving them a thorough washing under running water. Cleaning vegetables with skins, such potatoes and apples, can work better when done using a brush.

- **Peeling:** Peeling fruits and vegetables can reduce pesticide residues, although it may also remove some nutrients and fiber.

2. **Diversify Your Diet:**

- **Variety:** You can lessen your risk of coming into touch with any one pesticide by eating a wide variety of fruits and vegetables. It also ensures that the intake of nutrients is balanced.

3. **Organic Options:**

- **Understanding Organic:** The use of artificial fertilizers and pesticides is restricted in organic farming. Organic produce usually has lower amounts of pesticide residues, while it may still include natural or non-synthetic pesticides.

- **Cost Considerations:** Despite their higher price tag, consumers who are concerned about pesticide residues tend to use organic products more frequently.

4. Stay Informed:

- **Resources:** One tool that consumers can use to make decisions about which produce goods may have greater levels of pesticide residue is the Environmental Working Group's (EWG) "Dirty Dozen" list.

- **Local and Seasonal:** Purchasing seasonal and local produce can occasionally lower your exposure to pesticides since local farmers could use fewer herbicides.

The Bigger Picture: Balancing Act

The challenge lies in balancing the benefits of pesticide use with the need to protect human health and the environment. Innovations in agricultural practices and pest management are ongoing, aiming to reduce reliance on harmful chemicals while maintaining high crop yields.

1. Integrated Pest Management (IPM):

- **What It Is:** In order to manage pests in a way that is both environmentally and financially sustainable, integrated pest management (IPM) integrates biological, cultural, physical, and chemical strategies.

- **Benefits:** This strategy encourages the use of natural pest predators and other non-chemical approaches while reducing the demand for chemical pesticides.

2. Advances in Technology:

- **Precision Agriculture:** Precision agriculture is one example of how technological advancements have reduced total pesticide use and minimized environmental effect by enabling more targeted application of pesticides.

- **Biopesticides:** The creation of natural source-based biopesticides provides an alternative to synthetic pesticides.

CONCLUSION

Two important components of our current food system are pesticide residues and food security. Pesticides are necessary to sustain food supply and security, yet there are legitimate health concerns about their residues. Effective management of this complex landscape can be achieved by following safety rules, being aware of the role that pesticides play, and making educated decisions as consumers. The objective is still to guarantee that we can eat food that is safe, nutrient-dense, and sustainable while also supporting a resilient and sustainable food system, even as farming techniques and technology change.

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Role of Agriculture in Carbon Sequestration

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ABSTRACT

Agriculture plays a pivotal role in mitigating climate change through carbon sequestration, a process where carbon dioxide (CO_2) is captured from the atmosphere and stored in soil and plant biomass. Sustainable agricultural practices such as conservation tillage, cover cropping, agroforestry, and organic farming enhance soil organic carbon (SOC) levels, improving both carbon storage and soil health. Croplands, grasslands, and forests act as significant carbon sinks, with the potential to offset greenhouse gas (GHG) emissions. Additionally, carbon sequestration in agriculture supports biodiversity, water retention, and nutrient cycling, contributing to overall ecosystem resilience. However, challenges such as land degradation, deforestation, and unsustainable practices can reduce the efficacy of agriculture in sequestering carbon. Effective policies, carbon farming initiatives, and technological advancements are essential to maximizing agriculture's role in combating climate change.

INTRODUCTION

The average global temperature is increasing with each passing year. According to NOAA, Global Climate Report: July 2024, from January to July the global surface temperature reached 1.28°C (2.30°F). Scientists believe that if the temperature rises above 1.5 °C by even half a degree it will seriously aggravate the risk of drought, floods, extreme heat, etc which will in turn bring poverty to millions of people around the globe (The Guardian, 2018). The term Global warming refers to the increasing levels of GHGs in the atmosphere: CO_2, CH_4, N_2O, and fluorinated gases (F) (Filonchyk *et al*., 2024).

The emission of GHGs is attributed to fossil fuel combustion, industrial and agricultural activities. According to the IPCC, The removal or diversion of carbon dioxide from its emission source and its further storage in carbon reservoirs (known as, carbon sequestration) is a possible solution to combat climate change (USGS, 2011).

The agricultural sector occupies a large portion of global land area. The decomposition of SOM, crop residue burning, emission of methane under flooded rice cultivation and enteric fermentation in the digestive systems of livestock all contributes to GHGs emission (Jat *et al*., 2022). Scientists believe that the emission of GHGs from agriculture is manageable. Farmlands, in fact, even be made to absorb more gases than they emit, thus helping to absorb CO_2 emitted from fossil fuels and restore air quality. When this occurs the land acts as a "sink" or storehouse for C (Hutchinson *et al*., 2007).

1. Carbo sequestration: Definition

The process of capturing and long-term storing of atmospheric carbon dioxide is called "C sequestration". This CO_2 is stored in carbon pools. Carbon pool is simply a reservoir of carbon. A carbon pool can occur naturally or can be human made. Examples of carbon pool includes, forest biomass, wood products, soils, and the atmosphere. Carbon sequestration plays a crucial role in reducing global warming.

2. Agriculture in Carbon Sequestration

Around 2500 GT i.e., 80% of the terrestrial C is found in the soil. The process of Soil carbon sequestration involves transferring atmospheric CO_2 into soils via. crop residues. Zero tillage has also been reported to increase C sequestration in surface layers (Lal *et al.*, 2008). The storage of carbon in the soil provides various benefits. It increases SOM which results in increased crop yield and thereby increases farm income. The water quality improves due to reduced runoff and soil erosion, it increases soil biodiversity and makes soil resilient to extreme weather events. The role of photosynthesis and root respiration in fixing atmospheric CO_2, the formation of bicarbonate, its storage in groundwater or precipitation as $CaCO_3$ is a well understood mechanism under the C cycle (Dhanwantri *et al.*, 2014).

3.1 Reforestation and agroforestry

Forest acts as a "sink" for carbon. Activities like, afforestation, reforestation and agroforestry are natural and financially viable ways of carbon sequestration. It improves soil quality and increases soil C pool. Carbon is stored as plant biomass. But it must not be let to return to the atmosphere by burning (Dhanwantri *et al*., 2014). Forestry projects can bring social, economic, and local environmental benefits to millions of people (Dhanwantri *et al.*, 2014).

3.2 Soil C sequestration

Soil acts both as "sink" and "source" of carbon. Soil gains C by capturing it photosynthetically (referred to as NPP, net primary productivity) and from the recycling of a part of the NPP as crop residues, including root biomass, rhizodepositions or manure/organic waste. Soil loses C from plant respiration and the microbial decomposition and mineralization of organic residues to CO_2 and CH_4 (Jat *et al.*, 2022).

There are six management practices to increase SOC (Jat *et al.*, 2022).: (1) zero or minimum tillage practices, (2) establish and maintain a permanent ground cover, (3) intensification of nutrient recycling mechanisms, (4) maintain a proper nutrient balance, (5) biodiversity enhancement, and (6) reducing water and nutrients losses.

2.3 Microalgae carbon sequestration

The fixation of CO_2 and the production of algal biomass depends on the microalgae species. For C capturing certain freshwater microalgae such as *Scenedesmus*, *Spirulina platensis*, and *Chlorella* are commonly used. The cultivation of microalgae can fix 1.83 kg of CO_2 per kg, hence, offering a high potential for CO_2 sequestration. It was also shown that, CO_2 can be fixed at a rate of 6.24 g/L/d by *Chlorella vulgaris* and *Anabaena sp*. (Ighalo *et al.*, 2022).

Microalgal cells contain approximately 50%C, and 1 kg of microalgal biomass can be produced by fixing 1.8 kg of CO_2. There are two main pathways for carbon sequestration by microalgae (1) autotrophic pathway, inorganic carbon (i.e., CO_2): fixation through photosynthetic growth via the Calvin Benson cycle; and (2) heterotrophic pathway, which is the assimilation of organic carbon under the light-free conditions (Dahai *et al.*, 2024).

3.4 Proper land levelling practices

It is known to improve input use efficiency, crop growth, and yield. It lowers GHG emission by improving water and N use efficiency. It is also known to reduce nearly 0.15 Mg of CO_2-e ha^{-1} $year^{-1}$ of GHG emissions due to less time spent for pumping irrigation water and decreased cultivation time (Jat *et al.*, 2022).

3.5 Zero or minimum tillage

GHG emissions were reported to reduce by 1.5 Mg CO_2-e ha^{-1} $year^{-1}$ in zero tillage-based maize systems (Parihar *et al.*, 2018). Zero tillage practices stabilize soil aggregates and protects soil C from mineralization. Soil aggregates are stabilized under reduced and zero tillage practice, which physically protect C from mineralization (Jat *et al.*, 2022).

3.6 Crop residue management

Optimum use of fertilizer, rotation of paddy-upland, use of improved crop cultivars, and incorporating legumes in crop rotation are potential management practices for enhancing amounts of crop residue return to the soil. Biochar can stabilize decaying OM and reduce caron dioxide release from it. It can reduce upto 12 % of GHG emission. It also, decreases soil N_2O emissions (9–12% or even 50%). The presence of crop residue also ensures less requirement of fertilizer (Jat *et al.*, 2022).

3.7 Water management

The role of water management in C sequestration is associated with increasing NPP and the addition of biomass to soil. The increase in NPP is attributed to improved WUE. Proper water management also ensures reduced N losses (Jat *et al.*, 2022). It is estimated that improved water management could mitigate 1.14 t CO_2-e ha^{-1} year^{-1} of GHG emissions (Jat *et al.*, 2022).

3.8 Nutrient management and application of Organic Matter

The optimum and balanced application of fertilizer is known to enhance crop yield, improve NUE, and SOC storage, and mitigates GHG emissions. The placement of urea deep in the soil has shown to reduce N loss as thereby improving crop yield. This reduced N loss will in turn reduce GHG emission. Proper nutrient management can improve SOC content at the rate of 0.05–0.15 Mg ha^{-1} year^{-1} (Jat *et al.*, 2022).

In India, many initiatives have been taken by the government to improve soil health such as the National Mission for Sustainable Agriculture, Soil Health Card and Soil Health Management (SHM) program (Jat *et al.*, 2022).

The use of organic manure improves SOM by improving the health of soil microorganisms. However, application of inorganic nutrients (NPK) with FYM sequestered C at the rate of 0.33 Mg of C ha^{-1} yr^{-1} compared to 0.16 Mg of C ha^{-1} yr^{-1} in NPK application alone (Jat *et al.*, 2022).

3.9 Use of improved crop varieties

Certain Deep-rooted crops and crop varieties can sequester more CO_2 in lower soil profiles, reduces nitrate leaching and thereby reduces N_2O emission. Deep rooted crops have also been reported to reduce tillage requirements (Jat *et al.*, 2022). It is also reported that the association of mycorrhiza can provide up to 15% more C to soil. Hence, increasing C sequestration through "enhanced weathering" of silicate rocks via. intense interactions (Jat *et al.*, 2022).

3.10 Pest management

The excessive use of synthetic pesticides can increase GHG emissions. A possible solution to this is Integrated pest management (IPM) (Jat *et al.*, 2022). Studies have shown that IPM can enhance crop yield by >40%, and can reduce pesticide use by 31% (Pretty and Bharucha, 2015). In 2010, FAO recommended a Climate-smart pest management (CSPM) approach. Its aim to minimize yield losses due to pests, improve ecosystem services, reduce GHG emissions, and make the agricultural system more resilient (Jat *et al.*, 2022).

3.11 Use of cover crop

A cover can prevents nutrients leaching from the soil profile and reduce SOC loss. It is belived that, cover crops can reduce up to 8% of GHG emissions from agriculture. Studies have shown that cover crops and fallow rotation can reduce a net loss of 0.98 Mg C ha^{-1} in 7-year period (Jat *et al.*, 2022).

CONCLUSION

Carbon Sequestration helps in combating climate change. It helps in maintaining the natural carbon cycle. The role of agriculture in C sequestration is noteworthy. By appropriate management practices, GHGs emission from agriculture can be kept under control. The various means to achieve carbon sequestration from afforestation to use of algae for C fixation are being critically studied. The only need now is to implement these strategies properly.

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Precision Dairy Farming in India Prospects and Challenges

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ABSTRACT

Dairy farming, a labor-intensive sector, faces challenges in meeting global demand while maintaining sustainability and profitability. Precision dairying offers a transformative solution by using technology to monitor and manage individual cows. It optimizes production, reduces costs, and addresses labor shortages. Technologies such as data-capturing devices and sensor-based automation streamline tasks and provide real-time insights into cow health and productivity. Despite low adoption rates, precision dairying enhances efficiency, sustainability, and profitability. By enabling adaptive control and timely interventions, it has the potential to revolutionize dairy farming and ensure higher quality, increased production, and cost-effective practices for a sustainable future.

INTRODUCTION

A sector with a high labor need, dairy farming is under growing pressure to fulfil growing worldwide demand while preserving sustainability and profitability. A solution is provided by precision dairying, which optimizes production while cutting expenses by using technology to monitor and manage individual cows. Dairy farming has difficulties with labor scarcity and intricate herd management. These problems can be solved by precision technology, which can automate repetitive operations and provide real-time information on each cow's health and productivity (Maltz, 2000). Important technologies include data-capturing devices for tracking milk production, oestrus, and individual cow health, as well as sensor-based automation for jobs like feeding and milking. Precision dairying has the potential to greatly increase productivity, sustainability, and profitability in the dairy industry even if adoption rates are currently low.

Precision Dairy Farming's Future

Dairy farming with precision is transforming the industry by maximizing operations through the use of technology. Farmers can keep an eye on and manage variables including feed, health, and reproduction thanks to sensors and automation. Adaptive control and prompt interventions are made possible by real-time data. With the use of this technology, one may achieve higher sustainability, lower costs, better quality, and more production.

A Long-Term Fix

Precision dairy farming improves feed, reproduction, and animal welfare while also benefiting the environment. Modern technology lowers greenhouse gas emissions, trash, and antibiotic use. In addition to saving water, precision systems also reduce pollutants. In general, precision dairy farming encourages accountability and sustainability within the sector.

Increasing Profit and Productivity

Technology is used in precision dairy farming to enhance decision-making and boost productivity. Automation and real-time data support animal monitoring and issue detection. A sound understanding of the facts is essential for making wise judgements. Information systems that are integrated facilitate decision-making.

Improving the Health and Welfare of Animals

Precision dairy farming makes use of technology to keep a close eye on cows and identify health issues early. This proactive strategy guarantees the best possible treatment while lowering stress and illness. Customised meals are made possible by precision feeding, improving growth and nutrition. Animals live in a better habitat as a result, and output increases.

Supplying Superior Milk

By keeping an eye on important variables like feed, milk content, and animal health, precision dairy farming guarantees constant milk quality. Modern technologies aid in locating and resolving problems that compromise the quality of milk. Milk composition and output are optimised using precision feeding. High-quality milk is guaranteed and contamination is minimised in controlled surroundings. With this strategy, producers are able to satisfy customer needs for improved milk production.

A Manageable Resolution

As dairy operations expand, precision dairy farming becomes increasingly feasible. A greater dependence on improving the health and welfare of animals

Computer Ignorance: An Obstacle to Accurate Dairy Production

One of the biggest obstacles to the adoption of precision dairy farming is computer illiteracy. A lot of farmers, particularly those in rural regions, are not tech-savvy. This may result in challenges with transformation, learning, access, and data interpretation. To get beyond these obstacles and help farmers reap the rewards of precision dairy farming, training and assistance are crucial.

Opportunities and Challenges for Small Dairy Farms

Precision farming presents issues for small dairy farms. Obstacles may include high prices, restricted access to technology, a lack of workers, and a risk-averse mindset. Tailored solutions such as funding, collaborations, education, and government grants are required to solve these problems. This will enable small farms to take advantage of precision dairy farming even in the face of size constraints.

Ethical concerns may prevent precision dairy farming from becoming widely used. Obstacles may include worries about customer impression, automation ethics, data protection, and animal welfare. In order to ensure responsible adoption that serves the interests of both customers and animals, it is imperative that these issues be addressed through ethical norms, data security, education, and cooperation.

Difficulties with Human Resources in Precision Dairy Farming

One of the biggest obstacles to precision dairy farming adoption is a shortage of competent labour. Implementation may be hampered by labour shortages, specialised skills, training expenses, and change aversion. Precision dairy farming has to address these issues in order to have a sustainable future. Positive work environments, collaborations, training, and incentives can help.

Economic Data Absence: A Deterrent to Technology Adoption

Technology adoption may be impeded by uncertainty over the financial rewards. To promote investment, precise and quantitative statistics on economic benefit are necessary. Technologies may be marketed to prospective users more appealingly by using case studies, research papers, and cost-benefit assessments. Organisations can stimulate innovation by addressing this information gap.

Uncertainty in Economic Gains: A Problem for Precision Dairy Production

Precision dairy farming adoption may be impeded by uncertainty over the long-term financial gains. Farmers find it challenging to justify the investment due to changing costs, uncertain cost-benefit ratios, and regional disparities. Thorough investigation, tools for cost-benefit analysis, case studies, and monetary rewards can deal with these issues and promote broader acceptance.

SUMMARY

A sustainable response to the issues posed by climate change in the dairy sector can be found in precision dairy farming. This technique may drastically cut greenhouse gas emissions, preserve water, and minimise pollution by optimising feed management, reproductive efficiency, animal health, and resource utilisation. Because of this, precision dairy farming is an essential tool for creating a future that is more sustainable.

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Boosting Crop Yields with Zinc: The Ultimate Guide to Micronutrient Management, Soil Fertility, and Plant Health

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ABSTRACT

The magnitude of zinc insufficiency differs significantly across various soil types, leading to a 25–35% reduction in crop yield and quality. This, in turn, raises concerns about nutritional security in developing nations such as India, where cereals are a primary food source. Zinc insufficiency is a widespread problem in almost all crops and impacts a wide range of soil types, such as calcareous soils, intensively cultivated soils, rice fields, poorly drained soils, alkali and saline soils, mucky soils, soils with high phosphorus and silicon content, coarse textured soils, and also heavily weathered acidic soils. Additionally, phosphorus and copper have a negative interaction with zinc. Increasing zinc levels in crop plants has recently become a key objective due to the widespread consumption of zinc-deficient cereal products. The zinc content in plants varies based on species, variety, and physiological traits. The availability of zinc is affected by various factors, one of which are soil pH, density, moisture, and organic matter content. Consequently, both the quality and quantity of crop yields are heavily reliant on soil zinc levels. Precise knowledge of the zinc distribution in soils is essential for the optimal and productive administration of fertilizer resources.

INTRODUCTION

Zinc ions (Zn^{2+}) are vital nutrients with specific physiological roles in all living systems. Their primary responsibilities include preserving the organization and operation of protein synthesis, the expression of genes, enzyme structure, energy production, Krebs cycle, the breakdown of glucose, photosynthesis, auxin metabolism, pollen production, and resistance to specific diseases.

Additionally, Zn^{2+} has a beneficial effect on crop yield (Suganya *et al*. 2015). Hence, the quality and quantity yield of crops are well influenced through the availability of Zinc in the soil. Zinc insufficiency (49%) in soil is a global nutritional issue in agricultural output. The reason for the Zinc Use efficiency (ZUE) being less than 3.5% was determined to be variations in the Zn adsorptive capacity of the soils (Suganya 2015). Key limiting parameters including pH, electrical conductivity, organic carbon content, free lime status, and nutrient interaction significantly contribute to the reduction of ZUE. Over half of the soils in India lack sufficient amounts of zinc (Zn), making it imperative to enhance the availability of Zn in the soil by applying zinc fertilizers from several sources such as Traditional fertilizers, zinc chelated treatments, and natural organic compounds such as polymer-coated zinc. Recent research conducted by Zhang *et al*. (2013) and Hossain *et al*. (2008) have demonstrated that the zinc (Zn) concentration in maize grain can be increased by either applying Zn to the soil or priming the seeds with this element. The primary factor contributing to zinc shortage in plants is often inadequate availability of this element rather than soil insufficiency (Kalayci *et al*. 1999). Zinc availability is influenced by several parameters including soil response, density, moisture, and organic matter percentage (Chang *et al*. 2007, Sadeghzadeh 2013). The zinc concentration in plants varies and is influenced by the specific plant species, variety, and physiological traits (Cakmak *et al*. 1998, Oury *et al*. 2006).

Role of zinc in plant nutrition

- Zinc is the sole metal necessary for all six enzyme classes (oxidoreductases, transferases, hydrolases, lyases, isomerases, and ligases) (Singh *et al*. 2005a).

- Zinc is the constituent of three enzymes-carbonic anhydrase (Helps in transfer of CO_2/HCO_3^- for photosynthetic CO_2 fixation), alcoholic dehydrogenase (Plays important role in anaerobic root respiration), superoxide dismutase (Detoxifies superoxide radicals and protects the lipid and proteins of the membrane against oxidation).

- Zinc is indispensable for protein metabolism, and its greatest significance in protein synthesis lies in its contribution to the integrity and functionality of genetic information. (Singh *et al*. 2005a).

- Zinc has a vital physiological function in preserving the integrity and functional properties of cellular membranes by controlling the generation and elimination of reactive oxygen species (Mousavi, Galavi, and Rezaei 2013). The synthesis of tryptophan, a necessary condition for the production of auxin, is dependent on zinc. Consequently, a lack of zinc leads to a decrease in the quantity of auxin (Marschner 1995).

- Zinc plays a role in carbohydrate metabolism via influencing photosynthesis and glucose conversion. Impaired photosynthesis in the absence of zinc can lead to a decline in the activity of carbonic anhydrase (CA), the photochemical activity of chloroplasts, and the chlorophyll concentration, as well as changes in chloroplast structure.

- Zinc stimulates the production of cytochrome C.
- Influence of zinc on the translocation and transport of phosphorus in plants. P-toxicity occurs when there is an increased translocation of P under conditions of Zn-deficiency.

Deficiency symptoms of zinc in plant

Khaira disease in rice

White bud in maize

Little leaf in cotton

Frenching in citrus

Rosette disease in apple

Fern leaf in potato

Zinc deficiency in soil

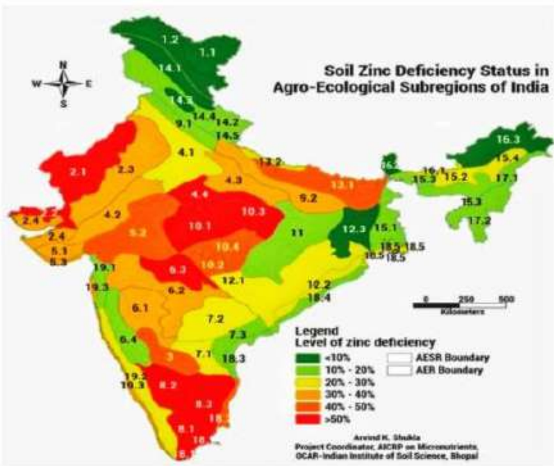
Over 50% of the agricultural soils in India suffer from zinc deficiency. The cumulative area affected by zinc deficiency in India is around 10 million hectares (Suganya *et al.* 2015). Insufficient zinc levels are widespread in the Indo-Gangetic plain and other significant cereal-producing regions such as Punjab and Uttar Pradesh, which contribute to around 75% of the nation's food grain output. In 2005, the zinc deficiency rates in Maharashtra, Karnataka, Haryana, Tamil Nadu, Meghalaya, Bihar, Orissa, Andhra

Pradesh, and Punjab were 86%, 72.8%, 60.5%, 58.4%, 57%, 54%, 49.4%, and 48.1% respectively (Singh 2009). Some reasons of zinc shortage in soils are enumerated below:

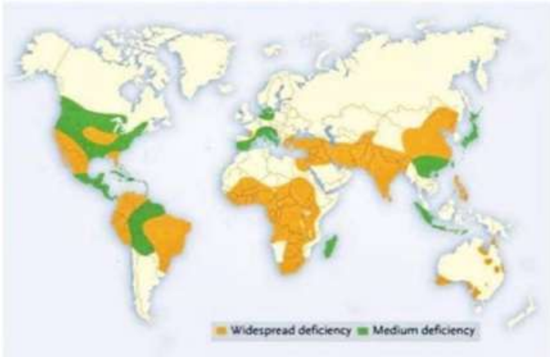
- Deficiency of zinc is common in soils that are neutral or calcareous, heavily cultivated, rice soil, poor-drained, sodic or saline, peat bog, high phosphorus and silicon availability, sandy, highly weathered acid, and coarse-textured.

- The occurrence of zinc deficiencies of this magnitude is attributed to the introduction of high-yielding varieties, failure to apply bulky organic manures, imbalanced fertilizer usage, and low zinc absorption mechanisms.

- Sandstone-derived soils exhibit a higher level of deficiency of zinc in comparison to those formed from limestone, shale, and igneous rocks. Granite-derived soils have been shown to contain greater levels of accessible zinc compared to soils generated from basalts and gneiss (Murthy 1988).



Zn deficiency in Indian soils (Shukla and Tiwari, 2016)



Zn deficiency in World soil (Alloway, 2008)

Factors affecting zinc availability in soil

There exist multiple factors that give rise to the condition of zinc shortage and toxicity. Zn availability in soil is influenced by several factors.

- ✓ **Parent material** – Soil derived from the parent material containing zinc are usually sufficient in available zinc depending on the weather condition**.** Soils formed from gneisses and granites often have low total zinc content, so do soils generated from sandstone and limestone (Barak and Helmke 1993; Pendias and Pendias 1992).

- ✓ **Texture -** The amount of zinc in lighter grained soils (sands) is rather low. Higher CEC values in finer texture soils, including clay, suggest the existence of highly reactive sites and a larger ability to retain Zn compared to lighter textured soils (Shukla and Mittal 1979; Suganya and Saravanan 2014).

- ✓ **Soil pH -** Zinc availability is strongly influenced by pH. At pH levels over 6, the availability of zinc is often significantly reduced. Decreased solubility of soil zinc diminishes the accessibility of zinc in alkaline soils. Therefore, the condition of zinc deficiency is more prone to occur in soils with an alkaline pH rather than an acidic pH.

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- ✓ **Organic matter -** Zinc shortage is caused by low levels of organic matter in soils, as it has been shown that the quantities of accessible zinc increase as the organic matter content in the soil increases (Hafeez, Khanif, and Saleem 2013).

- ✓ **Calcareousness -** Zinc solubility is negatively affected by the calcareousness of soil. The incorporation of zinc into the crystal structure of dolomite and magnesite occurred at certain positions in the lattice by replacing magnesium molecules. Furthermore, apart from its function in adsorbing soluble Zn, $CaCO_3$ also increases the likelihood of soluble zinc precipitating as $ZnCO_3$ and $Zn_3(CO_3)_2(OH)$ as the CO_3^{2-} concentration in soil rises (Hafeez, Khanif, and Saleem 2013).

- ✓ **Phosphate fertilizers** - Soils containing elevated concentration of phosphorus, either from natural phosphorus or from the use of phosphate fertilizers, can induce zinc deficiency stress in crops (Alloway, 2008a).

- ✓ **Eroded soil** – The depletion of readily accessible zinc is a consequence of soil erosion.

- ✓ **Lowland rice soil -** Waterlogging influences the zinc chemistry in lowland rice soil. For instance, submerged soils exhibit reduced levels of water-soluble zinc in comparison to well-drained soils.

- ✓ **Sewage-sludge** – Soil that receives untreated sewage sludge includes significant quantities of heavy metals, especially zinc, which gives rise to soil toxicity.

Management of zinc

Sphalerite (ZnO) is the mostly prevalent zinc-containing mineral found in soil. Additional zinc-containing minerals observed in the soil include smithsonite ($ZnCO_3$), willemite (Zn_2SiO_4), hemimorphite, and franklinite ($ZnFe_2O_4$). The predominant zinc fertilizer distributed in India is zinc sulphate heptahydrate ($ZnSO_4.7H_2O$), which ensures a minimum zinc content of 21%. Its monohydrate form, containing at least 33% zinc, reduces transportation and handling expenses. Typically, chelated zinc (Zn-EDTA), a free-flowing crystalline powder salt, ensures a minimum zinc content of 12%. The agronomical effectiveness of chelated-Zn is 4-5 times higher than that of zinc sulphate, but former is 15-20 times more expensive than the latter. Zincated urea and zincated phosphate are among the zinc-containing fertilizers listed in the fertilizer control order (FAI 2010). Application of zinc in the soil is a more favorable approach compared to less effective foliar sprays. Foliar treatment is an effective method to address zinc deficiency in a standing crop. Soil applied zinc is considered sufficient to fulfill the needs of 2-3 specific crops.

Table 1 provides the primary sources of zinc fertilizer (Alloway, 2008a; Mousavi, Galavi, and Rezaei 2013).

Zn compound	Formula	% Zn content
Zinc sulfate monohydrate	$ZnSO_4.H_2O$	36
Zinc sulfate heptahydrate	$ZnSO_4.7H_2O$	22
Basic zinc sulfate	$ZnSO_4.4Zn(OH)_2$	55
Zinc oxysulphate	$xZnSO_4.xZnO$	20–50
Zinc oxide	ZnO	50–80
Zinc carbonate	$ZnCO_3$	50–56
Zinc nitrate	$Zn(NO_3)_2.3H_2O$	23
Zinc phosphate	$Zn_3(PO_4)_2$	50
Zinc frits Fritted glass	Fritted glass	10-30

Ammoniated zinc sulfate solution	$Zn(NH_3)_4SO_4$	10
Disodium zinc EDTA	Na_2Zn EDTA	8-14
Sodium zinc HEDTA	NaZn HEDTA	6–10
Sodium zinc EDTA	NaZn EDTA	9–13
Zinc polyflavonoid	-	5–10
Zinc lignosulfonate	-	5-8

CONCLUSION

The topic emphasizes the major role that zinc plays in optimizing crop productivity and overall plant health. By ensuring adequate zinc levels in the soil through effective micronutrient management, farmers can enhance soil fertility, support plant growth, and improve resistance to diseases. Proper zinc supplementation not only increases yields but also contributes to food security and sustainable agricultural practices. Effective zinc management is a cornerstone of modern agricultural practices, promoting long-term productivity and plant health. Understanding and managing soil micronutrient balance is key to cultivate healthy, high-yielding crops for long-ter m agricultural success.

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Barnyard and Kodo Millet: Nutrients and Antioxidants

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ABSTRACT

Barnyard (*Echinochloa frumentacea* L.) and kodo (*Paspalum scrobiculatum* L.) millets are important minor millets of tropical and subtropical countries. These millets are small seeded and highly nutritious containing high dietary fibre and mineral content. In the present study, nutrient and antioxidant content of barnyard and kodo millets were analyzed. The calorific value of kodo millet was 332 Kcal, significantly higher than that of barnyard millet (329Kcal). Total carbohydrate (66.88±0.45 %) and moisture content (11.52±0.06 %) was higher in kodo millet whereas protein (11.50±0.12 %), fat (3.52±0.06 %), ash (4.23±0.19 %) and crude fibre (7.70±0.09 %) was higher in barnyard millet. Total polyphenols (1152.30±0.07 mg gallic acid equivalent/100g) and tannins (62.54±0.06 mg tannic acid equivalent/100g) were significantly higher in kodo millet. Hence, both barnyard millet and kodo millet exhibited better nutrient composition and antioxidant profile in terms of total phenols and tannins.

INTRODUCTION

Millets are small sized grains commonly used for food, feed or forage purpose. Millets are staple foods for African and Asiatic people. In developing countries like Asia and Africa, roughly 90 per cent millet production can be seen. Millets are rich in vitamins, minerals, sulphur containing amino acids and phytochemicals, and hence are termed as "nutri-cereals". Barnyard millet *(Echinochloa frumentacea* L.) is called by several names viz., *Oodalu, Sawan and Sanwank.* In India, it is cultivated is in Tamil Nadu, Andhra Pradesh, Karnataka, Jharkhand and Uttar Pradesh. Kodo millet [*Paspalum scrobiculatum* (L.)] is a tropical small millet crop, indigenous to India. It is believed that kodo was first harvested as a weed alongside other cereals. Nutritionally barnyard millet is an important crop. It is a fair source of protein, which is highly digestible (Kumar *et al*., 2010). Kodo millet is highly nutritious and a good substitute to rice or wheat (Muthamilarasan *et al*., 2015). Hence, the present study was undertaken with the objective to analyze 'the nutrient composition and antioxidant profile of barnyard and kodo millet.'

Materials and Methods: An investigation was carried out to study 'Nutrient composition and antioxidant profile of barnyard (*Echinochloa frumentacea* L.) and kodo (*Paspalum scrobiculatum* L.) millet'. Barnyard millet DhBM-93.2 was procured from Seed Unit, University of Agricultural Sciences, Dharwad. Dehusked kodo millet was procured from Millet Processing Unit, Timmapur, Haveri District. Barnyard and kodo millet were cleaned to remove dirt, stones and unhulled millets. Millets were coarsely ground and used for further analysis. For nutrient composition, proximate principles were analyzed by AOAC method (2005). DPPH (2, 2-diphenyl-1-picryl-hydrazyl) free radical scavenging, total antioxidant activity, phenols and tannins were analyzed using standard procedure. Student 't' test was applied to test the significance.

Results and Discussion: Nutrient composition i.e. proximate gives a knowledge regarding macronutrient content of the millets. Details of proximate composition are mentioned in Table 1. Protein, fat, ash, and crude fiber content of barnyard millet was significantly higher at 11.50±0.12, 3.52±0.06, 4.23±0.19 and 7.70±0.09 per cent respectively than that of kodo millet. Whereas moisture content was significantly higher in kodo millet (11.52±0.06 %) than barnyard millet (10.15±0.09 %). Total and available carbohydrate was significantly higher in kodo millet (66.88±0.45 and 72.56±0.34 % respectively) than barnyard millet (62.90±0.55 and 70.60±0.46 % respectively). The calorific value of kodo millet was 332 kcal which was significantly higher ($p<0.05$) than that of barnyard millet 329 kcal. The values are comparable with those reported by Thilagavathi *et al.* (2015). Slightly higher values for proximate composition were reported by Nazni and Devi (2016) and Shyam and Singh (2018) which may be due to the variations in varietal differences, geographical locations, agronomic practices and processing conditions (Nithyashree and Vijayalaxmi, 2023). Crude fibre is indigestible portion which contributes to digestive health. These compositions are important in determining nutritive value of foods and play an important role in formulating food products. Antioxidant content and activity of barnyard and kodo millet are presented in Table 2 and 3 (Figure 1 and 2). Total phenolic (1152.30±0.07 mg GAE/100g) and tannin (62.54±0.06 mg TAE/100g) content were significantly higher

($p<0.01$) in kodo millet. Barnyard millet had significantly lower total phenolic content of 694.88±0.08 GAE/100g and tannins content of 40.90±0.06 mg TAE/100g. 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity was significantly higher ($p<0.01$) for kodo millet that is 70.78±0.46 per cent followed by barnyard millet that is 58.77±0.42 per cent. Phosphomolybdenum activity of kodo millet (57.22±0.24 %) was significantly higher ($p<0.01$) than that of barnyard millet (49.54±0.33 %). Kodo millet had significantly higher antioxidant content, this may be because kodo millet was darker in color compared to barnyard millet. Arunima *et al*. (2021) reported that colored grains exhibit higher nutritional, antioxidant and health promoting properties. The higher total phenolic and tannin content of kodo millet resulted in significant higher antioxidant. Antioxidants act as radical scavengers by interfering with the oxidation process, thus preventing formation of free radicals. They exert their mode of action either by suppressing the formation of reactive oxygen species by inhibition of enzymes or by chelating trace elements (Shanmugapriya *et al*., 2011). Dietary phenolic compounds, tannins and flavonoids exhibit antioxidant and anticarcinogenic activities (Araceli *et al*., 2003).

CONCLUSION:

The study concluded that both barnyard millet and kodo millet have better nutritional composition with respect to proximate principles whereas kodo millet exhibits better antioxidant profile and activity. The nutritional value of these millets is comparable to major staple cereals such as wheat, rice and sorghum etc. Radical scavenging activity of millets suggests that they act as antioxidants by interfering as scavengers with the oxidation process, thus preventing formation of free radicals which further prevents disease formation. Dietary phenolic compounds and tannins present in these millets exhibit antioxidant and anticarcinogenic activities. Hence, these millets can be considered as potential crops for food and nutrition security.

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Table 1. Proximate composition of barnyard and kodo millet

Proximate (%)	Barnyard millet	Kodo Millet	t value
Moisture	10.15±0.09	11.52±0.06	21.94**
Protein	11.50±0.12	9.84±0.15	14.97**
Fat	3.52±0.06	2.81±0.05	15.75**
Ash	4.23±0.19	3.27±0.08	8.07**
Crude fibre	7.70±0.09	5.68±0.11	24.62**
Total carbohydrate	62.90±0.55	66.88±0.45	9.70**
Available carbohydrate	70.60±0.46	72.56±0.34	5.93**
Energy (kcal)	329	332	3.67*

Note: Values are expressed as mean ± standard deviation of three replications *Significant at 5% level**Significant at 1% level

Table 2 Antioxidant content of barnyard and kodo millet

Antioxidant content	Barnyard millet	Kodo millet	t value
Polyphenols (mg GAE/100g)	694.88±0.08	1152.30±0.07	38.42**
Tannins (mg TAE/100g)	40.90±0.06	62.54±0.06	33.24**

Note: Values are expressed as mean ± standard deviation of three replications **Significant at 1% level, GAE – gallic acid equivalent, TAE – tannic acid equivalent

Table 3 Antioxidant activity of barnyard and kodo millet

Antioxidant activity	Barnyard millet	Kodo millet	t value
% DPPH scavenging activity	58.77±0.42	70.78±0.46	33.47**
% Phosphomolybdenum activity	49.54±0.33	57.22±0.24	28.99**

Note: Values are expressed as mean ± standard deviation of three replications **Significant at 1% level, DPPH – 2,2 diphenyl-picryl-hydrazyl

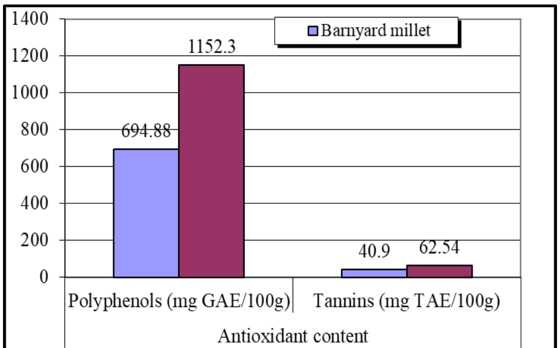

Fig. 1. Antioxidant content of millets

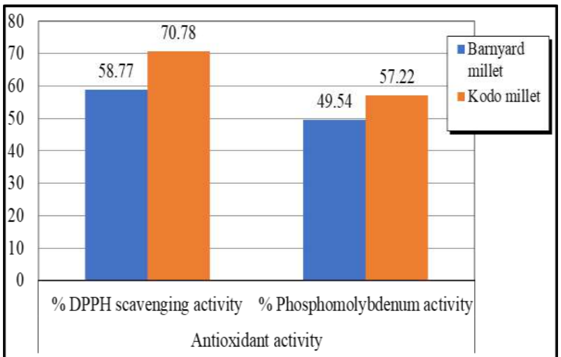

Fig. 2. Antioxidant activity of millets

Advancing Agricultural Sustainability with Endophytic Nanotechnology

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ABSTRACT

Agriculture productivity declines due to constant increase in population and drastic fluctuations in the environmental conditions worldwide. It poses burden to agriculture sector to meet the increasing food demand. Understanding the challenges and exploring new ways is crucial for sustainable agriculture. Endophytic nanotechnology offers a promising approach for addressing problems associated with modern agriculture practices. Endophytic nanotechnology combines the use of endophytes with nanotechnology to improve the plant health and productivity.Climate change, resource scarcity and soil degradation are some reasons of the poor agriculture productivity. Many technological advances are being utilized from decades to enhance the performance of agriculture sector. Still this sector needs innovation and exploration to face the future challenges. The integration of nanotechnology with endophytes can create a synergistic effect, leading to improved plant health, increased crop yields, and reduced reliance on chemical fertilizers and pesticides. Endophytes are the micro- organisms that reside within the plant system without causing any harm. These endophytes are having symbiotic relationship with plants and also responsible for the survival of the plant in various unfavorable conditions. Endophytes helps plant in nutrient uptake, stress tolerance and pest resistance. In the present study the potential applications of endophytic nanotechnology in enhancing plant growth, protecting against biotic and abiotic stresses, and promoting environmentally sustainable agriculture will be highlighted. However, further research is needed to fully realize the scope and impact of this innovative approach in sustainable agriculture.

INTRODUCTION

Global food demand continues to rise due to population growth but the production is struggling to keep pace. Agricultural production is affected due to shrinking of agriculture land area and constantly changing climate conditions especially in India. Various abiotic and biotic factors, i.e., intense rainfall, drought, floods and emergence of resistant pest have adversely affected the crop yield and livelihood of the farmers. To respond to the adverse effects of climate change scenarios, it is critical to invest in optimizing the climate-smart and resilient agricultural practices and technology advancement for sustainable productivity. Understanding the challenges and exploring new ways is crucial for sustainable agriculture. Endophytic nanotechnology offers a promising approach for addressing problems associated with modern agriculture practices. Endophytic nanotechnology combines the use of endophytes with nanotechnology to improve the plant health and productivity. Climate change, resource scarcity and soil degradation are some reasons behind the poor agriculture productivity. Many technological advances are being utilized from decades to enhance the performance of agriculture sector. Still this sector needs innovation and exploration to face the future challenges. Endophytic nanotechnology is an excellent example of the power of merger of nature and technology. Endophytes are the micro- organisms that reside within the plant system without causing any harm. Basically, these endophytes are having symbiotic relationship with plants and also responsible for the survival of the plant in various unfavorable conditions. Endophytes aiding plant in nutrient uptake, stress tolerance and pest resistance. Therefore, this technology influences the plant system strongly than other technologies. In this article challenges related to the agriculture sector, their possible technological solutions and the role of endophytic nanotechnology will be explored.

Challenges to the agriculture sector:

In the present scenario where, environmental changes occur vary rapidly due to anthropogenic activities, it creates ecological menace. Ecological balance is of utmost importance for agricultural productivity. Some key challenges due to climate change are summarized as follows:

- **Temperature extremes**: Extreme hot and cold conditions are not favorable to the crop yield and health. Extreme heat poses heat stress to the crop reduces the yield and also decreases the survival rate. Frost has also led to damage to the crop and reduced productivity.

- **Water availability**: Water scarcity is one of the most upcoming challenges due to global warming and diminishing water resources. Crop productivity is directly related to good irrigation practices. Shifts in rainfall patterns highly affect agriculture productivity.

- **Soil degradation**: Poor agriculture practices, micro/nano plastic contamination, and deforestation led to the loss of top soil that is necessary for plant growth. Microplastic accumulation alters many physiological processes in plants and also changes the soil microbiota.

- **Pest and disease pressure**: The emergence of new diseases inplantsis developed due to intensive changes in climate conditions and pollution in the ecosystem. Overuse of pesticides in agriculture develops resistant pest variety that threatens crop productivity. It increases the disease pressure on the crops and reduces overall productivity.
- **Biodiversity concerns**: Monoculture farming practices reduce biodiversity and makethe crop more vulnerable to pests and diseases.

To overcome existing challenges, breakthroughs in technological research and development are crucial, particularly in harnessing the unique properties of nanoparticles, such as their tunable size, tailored physicochemical attributes, and engineered optical properties. The multifaceted potential of endophytes extends to various sectors, including agriculture, horticulture, forestry, and environmental remediation, offering sustainable alternatives that reduce chemical inputs, promote food safety, and support ecosystem resilience. By leveraging endophytes' capabilities and nanoparticle technology, we can develop eco-friendly practices, enhance food quality, foster ecosystem biodiversity, and address environmental challenges. The synergistic integration of endophytes and nanoparticles will drive innovation, ensuring a sustainable future for agriculture, forestry, and environmental stewardship, with benefits including improved crop yields, efficient forest management, and effective pollution mitigation.

Endophytes: Microbial Allies

Microbes are the factories for various undiscovered things, so nanotechnology combined with endophytes is preferred over the other methods which can be deleterious. Endophytes are microbes that colonize plants in a mutualistic symbiotic relationship. They provide various benefits to the plants like promoting plant growth and increasing resistance against diseases and environmental stress. The biosynthesis of nanoparticles (NPs) from metal ions is a sophisticated, microbe-mediated process leveraging secondary metabolites and cellular enzymes. It unfolds through three pivotal stages: bioaccumulation (selective sequestration), bioreduction (enzyme-catalyzed NP formation), and stabilization (biomolecule-secured NP uniformity). This innovative pathway enables microorganisms to detoxify metal ions, yielding biocompatible NPs for medicine (targeted drug delivery, imaging), agriculture (sustainable crop protection), and environmental remediation (heavy metal removal). Key benefits include eco-friendly, sustainable production, high NP uniformity and stability, and scalability. Microbe-mediated NP biosynthesis offers a promising alternative to chemical methods, harnessing microbial potential for cutting-edge applications.

Endophytes exhibit remarkable diversity, characterized by varied life strategies, microbial types, and plant residency locations. Their life strategies range from obligate to facultative and opportunistic relationships with plants. Microbially, endophytes encompass bacteria, fungi, and actinobacteria. Furthermore, they colonize specific plant tissues, including roots, stems, leaves, flowers, and seeds, demonstrating habitat specificity. This complex interplay of life cycle completion, microbial taxonomy, and functional roles enables endophytes to play pivotal roles in plant growth, health, and resilience.

Types of Endophytes

Various kinds of endophytes are linked to plants such as fungi and bacteria which are capable of colonizing within the plant tissues. For example, Endophytes involve a wide range of spectra of bacteria ranging from gram-positive to gram-negative. It has been reported that there are beyond 200genera of bacteria that belong to 16 phyla of bacteria that are connected to the endophytes, like *Firmicutes*, *Proteobacteria*, and *Actinobacteria*. These various varieties of endophytes provide us with various bioactive metabolites that have the potential to act as antifungal or antimicrobial compounds. (Fadiji & Babalola, 2020).

They are sub-divided based onmicrobes' life strategies, types, and their location in the plants: -

Life strategies based

- **Opportunistic Endophytes:** Bacteria that occasionally enter plants for their own needs. These endophytes are generally known to live outside the plants and occasionally invade the plant tissues. They take advantage of the various nutrients from the plants, changing environmental conditions for their growth. Various examples are *Trichoderma spp*. (fungi), *Pseudomonas spp.* (bacteria)

- **Facultative Endophytes:** Bacteria that can optionally live inside plants and in other habitats are also optional plant inhabitants. They are involved in different mechanisms like Phytohormone production, Siderophore production, Nutrient uptake, and solubilization. For example: - *Enterobacter spp.(bacteria), Klebsiella spp*.(bacteria), *Trichoderma spp*. (Fungi).

- **Obligate Endophytes:** Bacteria that are restricted and strictly bound to life inside a plant. They are dependent on the plant tissue for reproduction. They are involved in different mechanisms like Cell wall modification and plant defense, Signaling, and communication with plant hosts. Some examples are *Rhizobia*-legume symbiosis (soybean, pea,*and Mycorrhizal* fungi-plant associations (oak, pine).

Types of microbes:

- **Bacterial Endophytes:** Bacteria that live inside the plant tissue without causing any harm. They are found in all parts of the plants like seeds, stems, leaves, roots, etc. They provide several benefits like plant growth promotion, drought tolerance, and water relations, defense against pests and diseases. Examples: Rhizobia-legume symbiosis (soybean, pea).

- **Fungal Endophytes:** Fungi that live inside the tissue of the plant and give various benefits to the host. They are a rich source of several secondary metabolites and also produce bioactive compounds. Examples: *Trichoderma spp.* (biocontrol agent)

- **Actinobacterial Endophytes:** Group of microbes belonging to the phylum actinobacteria that live inside the plant body and do not cause any harm. They are known for their vital role in promoting growth and generating a rich spectrum of bioactive natural products. Example: *Streptomyces coelicolor* (antibiotic producer) etc. (Afzal *et al*., 2019)

- **Protistan Endophytes:** Group of endophytes that belong to the kingdom Protista and live in the host boy in a symbiont relation. They are involved in different mechanisms like symbiotic nutrient exchange, hormone regulation, etc. Notable protistan endophytes include *Plasmodiophora brassicae.*

Plant location based

- **Leaf Endophytes:** The endophytes that live inside the leaf tissue of the plant.These endophytes are known for their role in the evolution and adaptation of plants in the environment and protection from their natural enemies. Examples: *Pseudomonas syringae* (biocontrol agent)

- **Stem Endophytes:** The endophytes that live inside the stem tissue of the plant. Stem endophytes play a crucial role in root development, photosynthesis, etc. Some examples are *Bacillus amyloliquefaciens* (plant growth promoter).

- **Root Endophytes:** The endophytes that live inside the root tissue of the plant. These endophytes regulate several nutrient uptake in the soil. *Legumes (e.g., soybeans, and peas)* are important plant hosts.

- **Seed Endophytes:** The endophytes that live inside the seed tissue of the plant. These endophytes have the ability to improve the seed germination and the plant growth. Examples of seed endophytes are *Paenibacillus.* (Choudhary *et al*., 2023)

Synthesizing nanoparticles from endophytes

In the current scenario, Nanoparticles are widely used in the field of agriculture, which involves various types of nano pesticides, nano fertilizers, and so on. Even though we can achieve a successful synthesis of NPs by utilizing chemical and physical methods, however, due to their apparent drawbacks, the researchers are veering toward the green synthesis or biological synthesis of NPs via utilizing various kinds of microbes such as bacteria, fungi, yeast, and algae.

Green synthesis of NPs is not only eco-friendly but also less expensive and reduces the production of toxic compounds too. Nowadays utilization of endophytic microbes for the synthesis of NPs is extensively used because of their incredible properties such as enzymes and secondary metabolites secreted by these microbes are important for the reduction of metal ions into nanoparticles and therefore detoxifying the metals. This whole process takes place both in the extracellular and intracellular way. E.g. AgNP production: Size of 22 to 45 nanometers and a spherical shape synthesized intracellularly using Ag-Ag-resistant *B. safensis* etc. (Gezaf *et al*., 2022a)

Electrostatic interactions between the positive and negative charges of metallic ions on the microorganism's cell wall occur during intracellular production. Therefore, causing the reduction of the metal ion (M^+) to its metallic form (Mo). This process is catalyzed by microbial reductases that rely on cofactors such as nicotinamide adenine dinucleotide phosphate (NADPH) and nicotinamide adenine dinucleotide (NADH), which serve as electron carriers in oxidation-reduction reactions. Consequently, proteins in the periplasmic space or cytoplasm coat the nanoparticles, thereby stabilizing them.

During the extracellular. The supernatant of the culture, cell-free extract, or biomass is used in combination with the solution of metal while nanoparticles are formed outside the cell of the microorganisms. Microbial cells, aided by cofactors, release reductases into the culture medium, where they facilitate the synthesis of nanoparticles. This process involves nucleation and bio-reduction, followed by stabilization of the resulting nanoparticles through the use of capping agents. (Gezaf *et al*., 2022b)

Endophytic Nanotechnology for Stress Improvement

The application of nanomaterials has revolutionized plant stress management, significantly enhancing crop yields. Abiotic stress can have devastating effects on plants, including membrane damage, oxidative stress,

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and stunted growth. Fortunately, nanomaterials can help mitigate these impacts, promoting healthy plant growth. Endophytic microbes have emerged as valuable allies in this process, synthesizing nanomaterials that support plant well-being through various mechanisms. These beneficial microbes can fix nitrogen, produce siderophores, synthesize phytohormones, and produce enzymes, all while avoiding harmful effects. By leveraging these nanoparticle-synthesizing endophytes, we can bolster plant resilience to abiotic stresses, unlocking sustainable agricultural solutions. The rise of nano-growth enhancers, such as nano-biofertilizers and nano-pesticides, offers a promising eco-friendly alternative to traditional agrochemicals. As we continue to explore the intersection of nanotechnology and agriculture, we may uncover new strategies for protecting plants from oxidative stresses and ensuring a more sustainable food future.

In a more sophisticated level of response, plants employ advanced strategies to cope with stress, including the precise regulation of stress-associated genes and the deployment of protective proteins that safeguard cells against damage. Additionally, secondary metabolites orchestrate a range of physiological processes to alleviate abiotic stress, such as:

- Initiating polyamine biosynthesis to bolster stress resilience

- Activating signal transduction pathways to shield against ROS-induced damage

- Stabilizing cellular structures and protecting photosynthetic systems from oxidative stress

These intricate mechanisms empower plants to adapt and flourish in adverse environmental conditions.

Using nanoparticles or several endophytes alone can boost plant growth by improving nutrient availability and uptake, and by regulating plant growth regulators, especially in environments contaminated with heavy metals. However, combining endophytes with NPs-based remediation can overcome the limitations of each method and significantly enhance phytoremediation efficiency. Some of the examples:

- The use of nanoparticles in enhancing Pb phytostabilization and phytoaccumulation in *Lolium perenne* L.

- Zinc oxide nanoparticles (ZnO nanoparticles) have gained considerable attention as a promising tool, demonstrating significant potential in effectively addressing both biotic and abiotic stresses

- Bradyrhizobium, Rhizobacteria containing stress-induced ACC deaminase obtained from legume crops have proved effective against stress conditions like High temperature, Drought, and salinity.

- Pseudomonas strains PF1, obtained from rice have shown good results against salinity stress.

- Copper nanoparticles combined with Streptomyces capillispiralis have shown antibacterial activity against *Escherichia coli*.

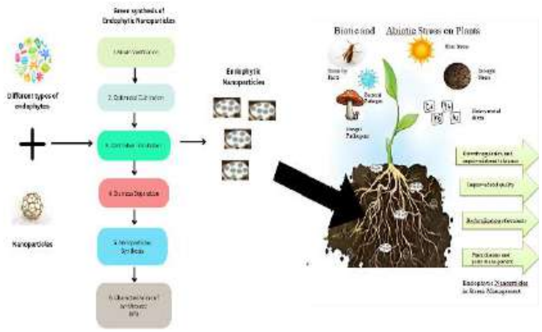

Figure 1: - Green synthesis of Endophytic NPs and their function.

Advantages of Endophytic Nanotechnology in the agriculture sector:

- Enhancement of shelf life of agroproducts by nanocoating: Several endophytic nanoparticles are used as components in edible coating and films which are applied to agroproducts for enhancing shelf life and storage quality.

- Plant disease management: The green synthesis of the nanoparticles in the development of targeted pesticides and biomolecule delivery systems are sustainably used for disease management.

- Growth regulation: Certain endophytic microbes are capable of synthesizing nanomaterials that support and improve plant health and growth through processes like nitrogen fixation, siderophore production, phytohormone synthesis, and enzyme production, all without causing any harmful effects.

- Biofortification of nutrients: Nanoparticles can regulate the absorption of nutrients in plants, and can be used in seed priming, soil application, and foliar application.

Potential Disadvantages

- Risk of nanoparticle accumulation in soil and water, toxicity to non-target organisms.

- Disruption of the local microbial community.

- Development of the pesticide-resistant pathogens.

- Limited understanding of nanoparticle-plan–plant interactions and limited access to exploiting these.

Future Perspective

- **Enhanced Crop Production:** With increasing climate changes around 40% of crops are affected by biotic as well as abiotic factors. For example: The use of Ti02 enhances fertilizer efficiency by controlling the release of nutrients, resulting in increased yield, growth, and photosynthesis activities.

- **Bioremediation:** Endophyte-nanoparticles interactions and optimization for heavy metal remediation, wastewater treatment, and phytoremediation enhancement. Examples: ZnO NPs increasing endophytic fungal degradation of heavy metals

- **Smart Agriculture:** Integrating omics approaches for endophyte nanoparticle interactions in smart techniques like sensors and monitoring systems, Precision irrigation, and fertilization.

- **Sustainable Practices:** The microbe mediated green synthesis provides a reliable eco-friendly alternative for producing nanoparticles as a substitute for traditional methods which can be hazardous. The unique properties of these nanoparticles offer targeted agrochemical delivery, ensuring crop yields and protection.

- **AI and Machine Learning:** Artificial Intelligence and endophytic nanotechnology in combination enable better data acquisition and improved design of nanomaterials. This combination is used for early disease detection and prevention, and reinforcement learning for optimized nanoparticle delivery. *(Zhang et al.*, 2021)

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CONCLUSION

Endophytes have undeniably demonstrated their significant benefits, positively impacting plants, the environment, and humans in various ways. These microorganisms can produce bioactive metabolites and essential industrial enzymes, enhance plant growth, perform biotransformation processes, and facilitate phytoremediation or bioremediation. To fully harness these endophytic capabilities, a comprehensive approach is needed to study endophytic systems and identify the most beneficial interactions between plants and microorganisms. The size-dependent properties of nanoparticles make them attractive for applications in agriculture. Investigating the endophyte-plant relationship in terms of survival mechanisms and responses to environmental conditions can help determine which plants are most promising for exploring valuable endophytic components and further synthesis of beneficial secondary metabolites or nanoparticles. Advanced biotechnological tools, such as molecular studies, can provide deeper insights into endophyte ecology, metabolic functions, and plant-endophyte interactions. A thorough understanding of this field could drive product development and have significant economic and environmental benefits.

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