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Recent Applications of Remote sensing in Agriculture-A Review

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Abstract

Remote sensing is becoming a crucial technology in current agricultural practices, with several uses and benefits for farmers, researchers and policymakers. Crop monitoring and management are the principal applications of remote sensing in agriculture. Remote sensing allows for the rapid and precise diagnosis of crop health, growth and yield estimation by evaluating data received from satellites or airborne platforms. This data assists farmers in optimising irrigation, fertilization, pest and disease control measures, resulting in better resource allocation, enhanced productivity and lower environmental consequences. The identification and mapping of crop diseases and pests is a key application. Remote sensing may detect minute differences in plant physiology, such as chlorophyll content changes, which may signal the presence of diseases or pest infestations. Initial identification allows for focused treatments such as precision pesticide application, disease avoidance and crop loss reduction. Precision agriculture relies heavily on remote sensing. Farmers may produce precise field maps that delineate differences in soil qualities, nutrient levels, and moisture content by integrating satellite photography, GPS navigation systems and computer algorithms. This data enables site-specific management, allowing farmers to deploy resources precisely where they are required, optimising inputs, lowering costs and minimising environmental consequences. Remote sensing makes land-use planning and monitoring easier. It can assist in identifying potential agricultural sites, assessing land degradation and tracking changes in land cover and land use trends over time. Policymakers can use this data to make informed decisions about land management, sustainable agriculture practices and conservation activities. It helps with agricultural water resource management. It is feasible to monitor water availability, assess irrigation demands and identify locations vulnerable to drought or water stress by studying satellite data. This information allows for more efficient water distribution, reducing water waste and improving water-use efficiency in agricultural activities. Remote sensing has numerous uses in agriculture, revolutionizing old farming practices.

Keywords: *Artificial intelligence, Precision agriculture, Remote sensing, Satellites, Spectral reflectance, Sustainability*

Introduction:

The ever-increasing population and urbanization are leading pressure on limited natural resources that are available for the production. The Sustainable Development Goals (SDGs) prioritize achieving global food security. This goal seeks to boost sustainable agriculture production, reduce food losses and waste, enhance nutrition, and end all forms of hunger. With a global population of 7.5 billion, 700 million people still lack access to food. By 2050, the world's food output must increase by 50% to meet demand. This will require increasing farmland acreage and irrigation water use, which currently accounts for almost two-thirds of the world's water supplies.

Food security is a major challenge in many nations, especially developing countries. This is due to a number of factors, including poor resource management, inadequate laws governing the use of food and irrigation water, climate change, and land degradation.

Climate change is expected to further impact crop yields, making it difficult to manage food and water systems. Extreme events such as

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floods and droughts can affect food availability, access to safe food, food prices, and sustainable food use. Climate change can also lead to prolonged droughts, increased reliance on groundwater, and a shift from irrigated to rainfed agricultural systems. Excessive watering can lead to crop lodging, salinity, and stunted crop growth. Pests and diseases can also significantly reduce agricultural yields. To increase productivity per unit area, farmers are adopting high-input agriculture, which can create problems for natural resources, the environment, and human health.

Therefore, there is a need for monitoring agriculture production systems to ensure that they are sustainable and do not harm the environment. Sustainable agricultural practices, improved irrigation and storage systems, and crop varieties that are resistant to floods and droughts are essential to addressing these challenges. By taking these steps, we can help to ensure food security for all.

Food security is a complex issue that requires both spatial and temporal management of crops. Traditional methods for monitoring crops are often labor-intensive and time-consuming. Remote sensing is a powerful tool that can be used to provide more accurate and timely information about crops.

Remote sensing is the acquisition of information about an object or area from a distance, typically from an aircraft or satellite. The use of remote sensing in agriculture is growing rapidly, as the technology becomes more affordable and accessible.

There are a number of satellites that are specifically designed for agricultural applications, and these satellites provide high-resolution data that can be used to monitor crops at a variety of scales. Remote sensing can be used to improve food security in a number of ways. For example, it can be used to: Identify areas of the cropland that are at risk of drought or flooding, monitor crop health and identify areas that are affected by pests or diseases, assess crop yields and identify areas that are underproducing, Plan irrigation and fertilizer applications, manage water resources, Track changes in land use and vegetation cover, Study the impact of climate change on agriculture.

Remote sensing is a powerful tool that can be used to improve food security. As the technology continues to develop, it is likely that its use in agriculture will become even more widespread.

What is remote sensing:

Satellite remote sensing is a technology that uses electromagnetic radiation to collect data about the Earth's surface. It emerged as a successor to aerial remote sensing in the 1960s, with the launch of the Explorer, TIROS (Television Infrared Observation Satellite), Corona and Landsat missions.

The process of satellite remote sensing begins when electromagnetic radiation interacts with the Earth's surface, either from the Sun or from the satellite itself. The radiation is reflected, absorbed, or transmitted and the Satellite sensors take measurements of the amount of radiation that is reflected. This reflected radiation contains data about the terrestrial activities that are currently happening at the location of the satellite overpass. Terrestrial processes encompass hydrological cycle components, vegetation processes, associations with water bodies, geomorphology and topography. Each of these procedures may be responsive to electromagnetic radiation measurements only at particular wavelengths or frequencies. Therefore, it is important to locate satellite sensors that are suitable for the task of monitoring a particular terrestrial process.

In addition to the wavelength or frequency of the radiation, the spatial, temporal, spectral, and radiometric resolutions of the satellite sensor also influence the quality of the data that is collected. Spatial resolution refers to the size of the smallest object that can be detected by the sensor. Temporal resolution refers to revisit time for images are collected. Spectral resolution refers to the number of different wavelengths or frequencies of radiation that the sensor can measure. Radiometric resolution refers to the accuracy with which the sensor can measure the amount of radiation that is reflected. The development of satellite remote sensing has revolutionized the way that we monitor the Earth's surface.

Satellite sensors record reflected radiation spanning the electromagnetic spectrum at multiple wavelengths. These wavelengths are normally range from visible/optical (0.4–0.7 µm wavelength), infrared (IR) (0.7–1.3 µm, 1.3–3.0 µm, and 3.0–14 µm wavelengths), and microwave (1 mm–1 m wavelength). This section contains a list of satellite sensors (Table 1) as well as information on their duration, geographic and temporal resolutions.

Table 1: Comprehensive overview of the different types of satellite sensors and their capabilities

Sensor name	Wavelength range	Spatial resolution	Temporal resolution
Landsat (Multispectral Scanner System (MSS)	500 nm – 1.1 µm (4 for Landsat 1,2,3, 4, and 5)	57 m, or 60 m	18 days, 16 days
Satellite pour l' Observation de la Terre (SPOT)	High Resolution Visible (HRV): 500 nm – 900 nm. High Resolution Visible and Infra-red (HRVIR) 500 nm – 1.75 µm	20 m 20 m; 10 m	26 days 26 days
IKONOS	Multispectral Sensor; Panchromatic Sensor 445 – 900 nm	3.2 m, 0.82 m	3 days
Terra, Aqua	Moderate Resolution Imaging Spectroradiometer (MODIS), 400 nm – 14.4 µm	250 m, 500 m, and 1 km	16 days
QuickBird	Multispectral Sensor; Panchromatic Sensor 450 – 900 nm	2.62 m, 0.65 m	1 – 3.5 days
ENVISAT	Medium Resolution Imaging Specrometer Instrument (MERIS) 390 – 1040 nm	300 m; 1200 m	35 days

RADARSAT-2	Synthetic Aperture Radar (C-band) 5.405 GHz (1)	3–100 m	24 days
TerraSAR-X	SAR-X 9.65 GHz (1)	1.1 m (SPOTLIGHT); 3.3 m (STRIPMAP); 18.5 m (SCANSAR)	11 days
RISAT-1	C Band Synthetic Aperture Radar (SAR) 5.35 GHz (1)	1 – 50 m	25 days
Sentinel 1A and 1B C-band	Synthetic Aperture Radar 5.405 GHz	5 m × 5 m (strip map mode), 5 m × 20 m (interferometric wide swath mode), and 25 m × 100 m (extra-wide swath mode); 5 m × 20 m (wave mode)	12 days

Applications of RS in agriculture:

RS is a valuable tool for farmers and agricultural professionals to monitor crop growth, health, and estimate yields, aiding in better crop management decisions. It can also map soil properties, optimize fertilizer and irrigation practices, monitor water resources, identify pests and diseases, and implement control measures early. RS can also be used for land use planning, climate change adaptation, and precision agriculture, enabling better decision-making and increased yields and profits. Overall, RS is a valuable resource for farmers and agricultural professionals, enhancing their crop management strategies and overall agricultural success.

Crop type and health:

Remote sensing can be used to identify different types of crops and to assess their health. The different crops have different reflectance's which are known as spectral signatures. The identification of crops helps in maintaining of crop inventory, yield prediction, crop rotation of area and sustainable management practices. Accurate crop categorization and mapping is essential for sustainable land management. The mapping of the crops requires the best input data and classifier method, especially in regions with limited field data. We use two-step processing chain that uses the intra-annual variance of temporal signals from remotely sensed data and prior knowledge of crop calendars to categorize crops. First, we used different soft wares (SNAP, ERDAS, QGIS, Arc Map) to preprocess and analyze data received from the various platforms that capture within-season phenological variation. We then modeled the developmental stage of each crop using a create training samples. Second, we tested a number of classification techniques, including support vector machines, random forest, and decision fusion. The classification accurate up to 85 to 95 %. The crop yield is estimate by semi empirical models by corelating the vegetation indices (NDVI, EVI, SAVI (Soil Adjusted Vegetation Index) and GVI (Green Vegetation Index)) and biophysical parameters (LAI and biomass) and empirical crop models.

The crop monitor is important to assess the impact of crop health. The health is mainly influenced by abiotic (water stress, environmental factors) and biotic factors (pest, weeds and diseases). The spectral reflectance of the crops varies when there is stress. The temporal profile of infected crop is less when compared to health crop. Diseases and pests can damage crops in four ways: by reducing biomass, developing lesions or pustules, destroying leaf pigments, or wilting plants. These pests and diseases can be detected by remote sensing at the leaf, canopy, and regional scales. Satellite remote sensing in optical and near-infrared (NIR) frequencies is routinely utilized on a regional scale to detect pests and diseases.

Fluorescence and microwave sensors have also been utilized for this kind of work, but most research have been confined to the leaf or canopy scale. Landsat, MODIS, Hyperion, and SPOT data, as well as information from multispectral and hyperspectral satellite sensors, have been proven to be useful for pest and disease identification. In addition to the commonly used vegetation indices, such as NDVI (Normalized Differential Vegetation Index), EVI (Enhanced Vegetation Index), NDWI (Normalized Differential Water Index), and LAI (Leaf Area Index), other indices have been proposed for pest and disease detection, such as the Disease Water Stress Index (DWSI) (Apan et al. 2004), Disease Index (DI) (Zheng et al., 2018), Yellow Rust Index (YRI) (Huang et al. 2014), Aphid Index (AI) (Luo et al. 2013), and Leafhopper Index (LHI) (Prabhakar et al. 2011).

These indices can be used to identify areas of the crop that are affected by pests or diseases, which can help farmers to take action to prevent further damage. Remote sensing is a valuable tool for pest and disease management, and it is likely to become even more important in the future as the demand for food production increases. Weeds are plants that compete with crops for nutrients and water, and can reduce crop productivity by up to 34% (Oerke 2006). Weeds can be detected using remote sensing, which can help farmers to identify and control weeds more effectively. Early studies used satellite sensors such as SPOT, Landsat TM, and AVHRR to identify weed-infested areas. However, these sensors have relatively coarse spatial resolution, which can make it difficult to detect small or patchy weeds.

More recently, researchers have used high-resolution satellite sensors such as QuickBird, Sentinel-2A, Landsat 8, SPOT-5, and Worldview-2 to detect weeds (Castillejo-Gonzalez et al. 2014). These sensors can provide reflectance information at very high spatial resolution (< 10 m), which makes it possible to identify individual weeds or small weed patches. In addition to using satellite sensors, researchers have also used vegetation indices to detect weeds. Vegetation indices are mathematical combinations of spectral reflectance bands that can be used to quantify the health and vigor of vegetation. Some vegetation indices that have been used for weed detection include NDVI, EVI, and NDWI.
Irrigation:

The ability to monitor irrigation on a wide scale is provided by satellite remote sensing. While monitoring irrigation, our primary research focuses on three elements.

a) Mapping of Irrigated area:

Optical satellite sensors are used to detect irrigation by analyzing the spectral patterns of irrigated and non-irrigated areas. These sensors can detect the difference in spectral reflectance between irrigated and non-irrigated areas, which can be used to classify irrigated and non-irrigated areas. In addition to spectral pattern analysis, optical satellite sensors can also be used to assess spatio-temporal variations of irrigation patterns by comparing images over time. This can be used to identify areas that are irrigated more or less frequently, which can help to improve water management. Accurate mapping of irrigated areas is essential for several reasons. First, it can help to ensure that water is allocated efficiently. Second, it can help to improve understanding of the water budget. Third, it can help to improve crop and hydrological models.

b) Quantification of irrigation water:

Quantifying irrigation water at large scales is challenging due to limited spatiotemporal information, technological and regulatory limitations, and the heterogeneity of agricultural systems. Irrigation estimates can be subject to substantial uncertainty due to the different practices used in different agricultural systems. Two techniques are used to calculate irrigation water usage: estimating irrigation water requirements (IWR) and estimating irrigation water consumption (IWU). IWR measures the difference between the quantity of water needed to regulate crop evapotranspiration losses (CWR) and effective precipitation (P). IWU measures the actual amount of water applied to crops. IWR is a useful tool for planning irrigation systems and managing water resources. However, it is important to note that IWR estimates can be inaccurate due to the variability of CWR and P. IWU is a more accurate measure of irrigation water usage, but it is more difficult to obtain.

c) Estimating irrigation water consumption (IWU) from soil moisture data:

Irrigation withdrawals from the source are often estimated, but they may not accurately reflect actual irrigation consumption due to under- or over-irrigation. Recent studies have focused on using soil moisture fluctuations in precipitation data to estimate IWU. The SM2RAIN method (Brocca et al. 2018; Jalilvand et al. 2019), which is applied to soil moisture products, has been used to quantify IWU by calculating the systematic discrepancies between precipitation from satellite soil moisture products and actual precipitation data. Other studies have attempted to calculate IWU by calculating the discrepancy between simulations of soil moisture produced by land surface models and simulations produced by including satellite soil moisture into land surface models.

Rootzone soil moisture measurement is essential for reliable IWU estimates. Rootzone soil moisture is the amount of water in the soil that is available to plants. By measuring rootzone soil moisture, it is possible to track how much water is being used by plants and how much water is being lost to evaporation or drainage.
Here are some additional examples of how remote sensing is being used in agriculture:

Precision Agriculture:

Remote sensing is critical in precision agriculture because it provides vital information on crops, soil conditions, and environmental elements. These are some significant remote sensing usages for precision agriculture:

a) Crop Monitoring:

Remote sensing enables growers to assess crop health and development across wide areas. Crop vigour, growth stages, and stress conditions can all be determined using satellite or aerial images. This information assists farmers in identifying areas that require care, like as nutrient deficits, pest infestations, or irrigation issues (Khanal et al. 2017; Hunt and Daughtry 2018).

b) Yield Prediction:

Growers can anticipate crop yields before harvest by analysing the data from remote sensing during the growing season. Predictive models for crop production can be constructed through the integration of data on vegetation indices, weather conditions, and historical yield data (Sishodia et al. 2020). This enables growers to make more informed decisions about storage, marketing, and financial planning.

C) Detection of Crop diseases and Pest Infestations:

Remote sensing can detect crop diseases and infestations of pests in advance, enabling prompt action. Sensors that detect slight variations in crop reflectance patterns caused by diseases or pests are known as hyperspectral or multispectral sensors. This information enables growers to execute customised treatment tactics, decreasing pesticide consumption and crop losses (Kumawat et al. 2023).

d) Soil mapping and management:

Remote sensing can help with the mapping of soil and characterisation by providing vital information about soil types, moisture content, and nutrient levels. Growers can create comprehensive soil maps and make accurate judgements on fertiliser application, irrigation timing, and farming practises by combining the data from remote sensing with ground-based measurements (Rebouh et al. 2023).

f) Irrigation Management:

Data from remote sensing, like thermal photography, can assist growers in optimising watering practises. Remote sensing allows farmers to identify the best times and locations to irrigate by assessing crop water stress levels, evapotranspiration rates, and soil moisture content. This ensures effective water usage and minimises water waste (Samreen et al. 2023).

g) Weed Detection and Management:

Weed infestations in agriculture fields can be identified by using remote sensing techniques. Farmers may discern between crops and weeds by analysing high-resolution pictures, allowing for tailored herbicide administration. This method reduces herbicide use while minimising environmental effect (Saranya et al. 2023).

h) Variable rate application:

Remote sensing data can be used to guide variable rate application of fertilisers, herbicides, and other resources. Farmers can administer inputs in a site-specific manner by analysing regional changes in crop health, nutrient deficits, or insect threats. This method optimises resource utilisation, lowers costs, and reduces environmental effect (Kumawat et al. 2023).

Disaster management:

Remote sensing is essential in many facets of disaster management. It entails gathering information about the Earth's surface by collecting and analysing data from aerial or spaceborne sensors. Here are some significant remote sensing applications in disaster management:

a) Damage Assessment:

Remote sensing aids in determining the degree and severity of natural catastrophe damage caused by earthquakes, hurricanes, floods, and wildfires. Authorities use satellite data and aerial photographs to compare pre and post-disaster circumstances, allowing them to identify affected areas, estimate damage, and prioritise response activities (Calantropio et al. 2018).

b) Emergency Response Planning:

Remote sensing data is useful for emergency response planning. It aids in the identification of vulnerable locations, such as flood-prone zones, landslide-prone areas, or places prone to forest fires. This knowledge enables officials to properly design evacuation plans, assign resources, and mobilise reaction squads (Damasevicius et al. 2023).

c) Hazard Mapping and Risk Assessment:

By identifying and mapping possible dangers, remote sensing aids in hazard mapping and risk assessment (Alarifi et al. 2022). It aids in the monitoring and analysis of elements such as land use, vegetation cover, slope stability, and water bodies, all of which are critical for assessing risk and identifying regions vulnerable to particular types of disasters.

d) Early warning systems:

Remote sensing data is utilised to construct early warning systems for a variety of calamities. Satellite-based sensors, for example, can monitor weather patterns, detect cyclones, and follow their movement, allowing for early warnings. Remote sensing can also be used to monitor river levels, detect changes in volcanic activity, or spot symptoms of an imminent landslide, allowing early warnings to be delivered to vulnerable people (Abdalzaher et al. 2023).

e) Flood monitoring and management:

Remote sensing techniques such as Synthetic Aperture Radar (SAR) and LiDAR can measure flood extent, monitor water levels, and estimate flood damage. This data aids in disaster response coordination, evacuation planning, and flood risk management (Sharma et al. 2019).

f) Forest Fire Detection and Monitoring:

Satellite photography is utilised to identify and track the progression of forest fires. Sensors that identify temperature anomalies and changes in vegetation health give real-time data to fire mitigation organisations, enabling them to prioritise firefighting activities and properly deploy resources (Tran et al. 2020).

g) Post-Disaster Recovery and Reconstruction:

Remote sensing aids in the recovery and rehabilitation activities following a disaster. High-resolution imaging aids in the identification of ideal areas for temporary shelters, the assessment of infrastructure damage, and the monitoring of rehabilitation work. During the rehabilitation phase, this information aids decision-making and the distribution of resources (Ghaffarian et al. 2021). Disaster management authorities can improve their preparedness, response, and recovery capacities by employing remote sensing technologies, reducing the effect of disasters and saving lives.

Climate change research

Remote sensing is critical in climate change research because it provides useful data and insights into numerous parts of the Earth's *climate system. Here are some significant remote sensing applications in climate change research:*

a) Monitoring Atmospheric Composition:

Remote sensing devices, such as satellites fitted with spectrometers, can be used to determine the chemical composition of the Earth's atmosphere. They collect information on greenhouse gases (such as carbon dioxide and methane), aerosols, ozone, and other trace gases (Wei et al. 2020). The results of these tests aid researchers in understanding fluctuations in atmospheric composition, tracking greenhouse gas sources and sinks, and assessing their effect on global warming.

b) Land Surface Change Observation:

Remote sensing offers information on land cover, land use change, and vegetation dynamics. Satellite imagery aids in the monitoring of deforestation, urbanisation, agricultural practises, and changes in vegetation production. This information is critical for comprehending the function of land surface changes in climate systems like the carbon cycle, albedo impact, and water cycle (Hussain and Karuppannan 2023).

c) Climate Simulation Validation and Calibration:

Climate models are validated and calibrated using remote sensing data. Satellite measurements are a useful tool for evaluating the correctness of model simulations, notably with regard to of air temperature, moisture, and cloud cover. These comparisons help boost the predictability and dependability of climate models (Sun et al. 2023).

d) Carbon Monitoring: Remote

sensing technologies aid carbon cycle research by assessing vegetation biomass and production. Satellite and aerial sensor data can be used to assess vegetation carbon stocks, follow forest changes, and predict carbon dioxide fluxes across the land surface and the atmosphere. This data contributes to an improved comprehension of carbon dynamics and the function of terrestrial ecosystems in the global carbon cycle (Jiao et al. 2021).

Climate researchers can improve their awareness of climate change processes, detect movements and trends, and promote evidence-based decision-making for adaptation and mitigation measures by using data from satellite observations.

Challenges of Remote sensing in agriculture:

Data availability and accessibility: Remote sensing data can be expensive and difficult to obtain, especially in developing countries. Additionally, the data may not be available in the right format or resolution for the specific application.

a. Data quality:

Remote sensing data can be affected by factors such as cloud cover, atmospheric conditions, and sensor noise. This can make it difficult to extract accurate information from the data.

b. Interpretation of data:

Remote sensing data can be complex to interpret, and there is often a high degree of uncertainty associated with the results. This can make it difficult to make informed decisions based on the data.

c. Lack of user skills and knowledge:

Remote sensing is a complex technology, and users need to have the skills and knowledge to interpret the data correctly. This can be a barrier to the adoption of remote sensing in agriculture.

d. Lack of integration with other data sources:

Remote sensing data is often used in isolation, but it can be more effective when it is integrated with other data sources, such as weather data, soil data, and crop yield data.
These are just some of the challenges of remote sensing in agriculture. However, there are also many potential benefits of using remote sensing, such as the ability to monitor crop health, assess crop yields, and map irrigation water use. As the technology continues to develop, these challenges are likely to be overcome, and remote sensing will become an increasingly important tool for agricultural management.

Future prospects of Remote sensing in agriculture:

Increased availability and accessibility of data: As the cost of RS data decreases and the availability of data increases, it will become easier for farmers and agriculturalists to use RS data to make informed decisions.

a. Improved data quality:

As RS sensors and data processing techniques improve, the quality of RS data will improve. This will make it easier to extract accurate information from the data and to make informed decisions based on the data.

b. Simplified data interpretation:

As RS software and tools become more user-friendly, it will be easier for farmers and agriculturalists to interpret RS data. This will make it easier for them to make informed decisions based on the data.

c. Increased integration with other data sources:

As RS data becomes more integrated with other data sources, such as weather data, soil data, and crop yield data, it will become more powerful tool for agricultural management.

d. New applications of RS:

As RS technology continues to develop, new applications for RS in agriculture will emerge. For example, RS could be used to monitor the impact of climate change on agriculture or to track the spread of pests and diseases.

These are just some of the future prospects of RS in agriculture. As the technology continues to develop, RS is likely to become an increasingly important tool for agricultural management.

Conclusion:

Remote sensing has the potential to revolutionize agriculture and help to ensure food security for a growing population. However, there are still some challenges that need to be addressed, such as the cost of data and the lack of user skills and knowledge. As these challenges are overcome, remote sensing is likely to become an essential tool for agricultural management. The future of remote sensing in agriculture is bright. As the technology continues to develop, remote sensing is likely to become an increasingly important tool for agricultural management.

Remote sensing data will become more widely available and affordable, making it easier for farmers and agriculturalists to use. Remote sensing sensors and data processing techniques will continue to improve, making it possible to extract more accurate and detailed information from the data. Remote sensing software and tools will become more user-friendly, making it easier for farmers and agriculturalists to interpret data and make informed decisions. Remote sensing will be more integrated with other data sources, such as weather data, soil data, and crop yield data.

This will make it possible to develop more comprehensive and accurate models of agricultural systems. Overall, the future of remote sensing in agriculture is bright. As the technology continues to develop, remote sensing is likely to become an increasingly important tool for agricultural management.

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COALITION OF AGRICULTURE IN AMBIANCE AMENDMENT

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ABSTRACT

Climate change is a pressing global issue that is affecting various sectors, and agriculture is no exception. The impact of climate change on agriculture is wide-ranging and poses significant challenges to food security, livelihoods, and the overall sustainability of agricultural practices. In this essay, we will explore the various ways climate change affects agriculture and the measures that can be taken to mitigate its adverse effects. One of the most significant impacts of climate change on agriculture is the alteration of weather patterns. Extreme weather events such as floods, droughts, heat waves, and hurricanes have become more frequent and intense. These events can damage crops, destroy infrastructure, and disrupt supply chains, leading to food shortages and price fluctuations. Moreover, unpredictable weather patterns make it difficult for farmers to plan their planting and harvesting schedules, affecting crop yields and productivity. Rising temperatures are another major consequence of climate change that affects agriculture. Higher temperatures can lead to the depletion of soil moisture, increased evaporation, and heat stress on plants and livestock. Many crops have specific temperature requirements for optimal growth, and exceeding these thresholds can lead to reduced yields and lower crop quality.

KEYWORDS: Climate, Drought, Crop Yield, Green House Gas, Livestock, Supply Chain

INTRODUCTION:

Climate change refers to long term shifts in temperature and weather patterns. This happens due to many internal and external factors mostly to the augment the level of atmospheric CO_2 produced by the use of fossil fuels, deforestation, burning crop residual, release of methane gas from rice field, power generation, and damage to biodiversity etc. Climate is a primary determinant of agriculture productivity. Change in climate expected to influence crop and livestock production, hydrologic balances, input supplies and other component of agriculture system (Ndaki.; 2016). As greenhouse gas emission in the atmosphere is increasing, the temperature is also increasing due to greenhouse effect. The average global temperature is increasing continuously and is expected to rise by two degrees Celsius until 2100 which would cause substantial economic losses at global level. The raise in temperature which leads to higher respiration rate, shorter period of seed formation and hence lowers down the biomass production. Climate change changes the incidence and distribution of pest and pathogens, increase rate of soil erosion and degradation, increasing tropospheric ozone level due to rise in temperature. The negative impact of higher temperature on reproduction can lead to reduced pollen production, viability, and pollen tube growth, with a resulting decrease in seed yield. Climate change also affects the microbial population and their enzymatic activities in soil .livestock can be affected by climate change by affecting the quality and amount of forage from grassland, decreasing in milk yield, heat stress and metabolic disorder, immune suppression, and other dairy operation.

There are two main strategies to reduce the impact of climate change i.e., adaptation and mitigation. Adaptation is the process of adjusting to the current and future aspects of climate change. Mitigation is the making the impact of climate change less severe by preventing or reducing the emission greenhouse gases into atmosphere. To control climate change start afforestation, stop using products which release CFCs to stop global warming and ozone depletion, accelerate energy efficiently and renewable energy use. Climate change leads to squat production of agriculture commodities leading to loss of economy and GDP of the country. Climate change is a “social dilemma” which has ill effects on human, plants animals and on our mother earth therefore; we must take precautionary measures to protect our environment.

Livestock may also suffer from heat stress, reducing their productivity and increasing the risk of diseases. Changes in precipitation patterns are also a concern. Some regions may experience more intense rainfall, leading to soil erosion, nutrient runoff, and water logging. In contrast, others may face prolonged periods of drought, resulting in water scarcity for irrigation and livestock. In both cases, agricultural productivity is adversely affected, and farmers face challenges in managing water resources efficiently. Additionally, climate change is altering the distribution and prevalence of pests and diseases. Warmer temperatures and changing precipitation patterns create more favorable conditions for certain pests to thrive, leading to outbreaks that can devastate crops and reduce yields. Similarly, warmer winters may fail to kill off certain pests, allowing them to survive and cause damage in subsequent seasons. New disease vectors may also emerge, posing risks to both crops and livestock. The impact of climate change on agriculture is not limited to crop production but extends to the broader agricultural value chain. Changes in crop yields and quality can affect food processing industries and lead to price fluctuations for consumers. Moreover, disruptions in the supply chain caused by extreme weather events can result in post-harvest losses and food wastage, exacerbating the food security challenges faced by vulnerable communities. To address the impact of climate change on agriculture, various adaptation and mitigation strategies can be employed. Promoting sustainable agricultural practices is crucial. This includes the adoption of climate-resilient crop varieties, crop rotation, agroforestry, and the conservation of water resources through efficient irrigation techniques. Precision agriculture, which utilizes technology to optimize resource use and monitor crop health, can also play a significant role in mitigating climate change’s adverse effects.

Another essential aspect is improving climate information and early warning systems to help farmers anticipate and prepare for extreme weather events. Access to weather forecasts and advisory services can enable farmers to make informed decisions about planting, irrigation, and pest control, reducing their vulnerability to climate-related risks. Furthermore, policymakers must invest in rural infrastructure, such as water storage facilities, roads, and markets, to enhance the resilience of agricultural communities. Financial support and insurance schemes can provide a safety net for farmers in the face of climate-related losses, encouraging them to adopt climate-smart practices.

GREENHOUSE GAS EMISSIONS

Agriculture is a substantial source of greenhouse gas emissions, contributing to global warming and climate change (Charles et al.;2013). The primary greenhouse gases associated with agricultural activities include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Here's how agriculture contributes to each of these gases:

a. Methane (CH4): Methane is produced in agricultural activities such as enteric fermentation in livestock (belching), manure management, and rice cultivation. Livestock, particularly ruminant animals like cattle and sheep, have specialized digestive systems that produce methane as a byproduct of digestion. Manure management practices, such as storage and decomposition, also release methane.

b. Nitrous Oxide (N_2O): Nitrous oxide is released from agricultural activities related to nitrogen use, such as synthetic fertilizers, manure application, and crop residues. These practices can lead to the release of nitrous oxide through a process called nitrification and denitrification.

c. Carbon Dioxide (CO_2): Agricultural practices contribute to carbon dioxide emissions through deforestation for agriculture expansion, land-use changes, and the burning of agricultural residues.

DEFORESTATION AND LAND-USE CHANGE:

Deforestation for agricultural expansion is a significant driver of greenhouse gas emissions. Forests act as carbon sinks, absorbing carbon dioxide from the atmosphere. When forests are cleared for agriculture, the stored carbon is released back into the atmosphere, contributing to global warming. Furthermore, the conversion of natural habitats into agricultural land reduces biodiversity and disrupts ecosystems, leading to ecological imbalances.

VULNERABILITY TO CLIMATE IMPACTS

While agriculture is a contributor to climate change, it is also highly vulnerable to the impacts of a changing climate. Here are some of the ways in which agriculture is affected (Liwenga et al; 2013).

a. Changing Weather Patterns: Climate change has led to shifts in weather patterns, including changes in precipitation, temperature, and the frequency and intensity of extreme weather events. These alterations can affect crop yields, water availability for irrigation, and livestock health.

b. Water Scarcity: Changes in precipitation patterns and increasing temperatures can lead to water scarcity, making it challenging for farmers to access sufficient water for irrigation and livestock.

c. Crop and Livestock Vulnerability: Rising temperatures and changing weather patterns can affect crop growth and the timing of plant development. Heat stress can reduce crop yields, and changing rainfall patterns can impact crop water requirements. Additionally, livestock may face health issues due to heat stress and an increase in pests and diseases.

d. Pests and Diseases: Climate change can alter the distribution and prevalence of pests and diseases, affecting crop and livestock health. New disease vectors may emerge, posing risks to food security and agricultural productivity.

e. Soil Erosion and Degradation: Extreme weather events, such as heavy rainfall and droughts, can contribute to soil erosion and degradation, reducing soil fertility and agricultural productivity.

MITIGATION AND ADAPTATION STRATEGIES:

To address agriculture's role in climate change and enhance its resilience to climate impacts, various mitigation and adaptation strategies can be employed:

a. Climate-Smart Agriculture: Implementing climate-smart agricultural practices, such as agroforestry, conservation agriculture, and integrated pest management, can reduce greenhouse gas emissions while enhancing productivity and resilience *(Nyasimi et. al.; 2020).*

b. Sustainable Land Use: Promoting sustainable land-use practices, such as reforestation, afforestation, and agroecology, can help sequester carbon and mitigate the impact of deforestation.

c. Improved Livestock Management: Sustainable livestock management practices, such as better feeding strategies, methane-reducing additives, and improved manure management, can help reduce methane emissions from livestock.

d. Efficient Water Management: Implementing efficient irrigation techniques, rainwater harvesting, and water-efficient crop varieties can help address water scarcity challenges in agriculture.

e. Diversification of Crops and Livestock: Diversifying crops and livestock breeds can enhance agricultural resilience to climate change by reducing reliance on a single commodity and making the system more adaptable to changing conditions.

f. Early Warning Systems: Investing in weather forecasting and early warning systems can help farmers anticipate and prepare for extreme weather events, reducing the risk of crop losses and other climate-related damages.

g. Research and Innovation: Continued research and innovation in agriculture are essential to develop climate-resilient crop varieties, improve farming techniques, and promote sustainable agricultural practices.

The Effects of drought, heat waves, flooding, an increase in pests and plant diseases, and decreased food yields and nutritional quality, climate change's effects on agriculture may reduce crop yields. Impacts of climate change make it more difficult for agriculture to provide for human needs. Global climate change is causing the consequences, which are unevenly spread throughout the planet due to variations in temperature, precipitation, and atmospheric carbon dioxide levels (Pauline et al.;2016).

Areas that are appropriate for farming will change as a result of temperature and weather changes. According to the present forecast, temperatures will rise and precipitation will fall across the Middle East, Africa, Australia, Southwest United States, and Southern Europe, which are all arid and semi-arid regions. Additionally, the projected moderate temperature increase (1-2 °C) anticipated to take place during the first half of the century will have a negative impact on crop yields in tropical countries. Crop yields are expected to decline across the board in the second part of the century, including Canada and the northern United States.

Many common crops are very heat-sensitive; for example, soybean seedlings die at temperatures over 36 °C, and maize pollen becomes lifeless. In several places of the world, especially Europe, heat waves that are likely related to climate change significantly decreased average yield. More crop failures in August led to an increase in food prices around the world. Governments and food firms were forced to release stored inventories because the output of wheat, rice, and maize was unable to keep up with demand. The CO2 fertilisation effect, also known as the carbon fertilisation effect, increases photosynthesis while decreasing leaf transpiration in plants.

Both processes are caused by higher levels of carbon dioxide (CO_2) in the atmosphere. The effect of carbon fertilisation varies depending on plant species, air and soil temperature, and water and nutrient availability. The carbon fertilisation effect may boost net primary productivity (NPP). However, data suggests that increased rates of photosynthesis in plants as a result of CO_2 fertilisation do not immediately improve all plant growth and consequently carbon storage. Carbon fertilisation has been reported to be responsible for 44% of the growth in gross primary production (GPP) since the 2000s. To investigate and forecast, Earth System Models, Land System Models, and Dynamic Global Vegetation Models are used (Yanda et al.;2021).

Changes in atmospheric carbon dioxide may affect the nutritional content of some crops, such as wheat, which contains less protein and fewer minerals. The nutritional content of C3 plants (such as wheat, oats, and rice) is severely jeopardised: decreased amounts of protein and minerals (such as zinc and iron) are expected. Protein, iron, and zinc content in popular food crops could be reduced by 3 to 17%. Infections already account for 10-16% of world crop, and this figure is expected to climb as plants become more vulnerable to pests and infections.

Warmer temperatures can boost an insect population's metabolic rate and number of breeding cycles. Insects that formerly had just two breeding cycles each year could obtain an extra cycle if warm growing seasons prolong, resulting in a population explosion. Insect populations are more likely to alter dramatically in temperate areas and higher latitudes. Some bug species will reproduce more quickly because they are more adapted to such shifts in conditions. *Spodoptera frugiperda*, or autumn armyworm, is a very invasive plant pest that has recently spread to Sub-Saharan African countries. Climate change is linked to the development of this plant pest, as specialists confirm that climate change is bringing more agricultural pests to Africa, and it is estimated that these extremely invasive crop pests will spread to other regions of the world due to their high adaptability to varied settings.

The autumn armyworm can cause extensive damage to crops, particularly maize, reducing agricultural productivity. Climate change has the potential to enhance the amount of arable land by decreasing the amount of frozen land. According to a 2005 study, the average temperature in Siberia has risen by 3x since 1960 (far faster than the rest of the world needs to be updated. However, assessments on the impact of global warming on Russian agriculture reveal contradictory likely effects although they anticipate a northward extension of farmable lands, they also warn of potential productivity losses and increased drought risk.

Warmer air temperatures recorded in recent decades are likely to result in a more active hydrological cycle, including more intense rainfall events. Erosion and soil degradation are more likely. Global warming would also have an impact on soil fertility.

Anthropogenic influences can cause increased erosion in agricultural landscapes, resulting in losses of up to 22% of soil carbon in 50 years. Soils will warm as a result of climate change. As a result, the size of the soil microbial population could expand by 40-150%. Warmer conditions would favour the growth of some bacteria species, altering the composition of the bacterial population. Elevated CO_2 levels would accelerate plant and soil microbial development, delaying the soil carbon cycle and favouring oligotrophs, which are slower-growing and more diverse. Flowering times have gotten earlier as a result of global warming, and early blooms can endanger the plant's life and reproduction. Early flowering raises the danger of frost damage in some plant species and causes 'mismatches' in plant blossoming and pollinator interaction. Around 70% of the world's most produced crop species rely to some extent on insect pollination, accounting for approximately 9% of agricultural production and contributing an estimated €153 billion to the global economy. Furthermore, milder winter temperatures induce many flowering plants to bloom, because plants require stimulation to flower, which is generally provided by a long winter frost. A plant cannot reproduce if it does not flower. However, if winters continue to get milder, plants may not get cold enough to experience the benefits.

CLIMATE SMART AGRICULTURE

Climate-smart agriculture (CSA) (or climate resilient agriculture) is an integrated approach to managing landscapes to help adapt agricultural methods, livestock and crops to the effects of climate change and, where possible, counteract it by reducing greenhouse gas emissions from agriculture, at the same time taking into account the growing world population to ensure food security. Thus, the emphasis is not simply on carbon farming or sustainable agriculture, but also on increasing agricultural productivity. "CSA is in line with FAO's vision for Sustainable

Food and Agriculture and supports FAO's goal to make agriculture, forestry and fisheries more productive and more sustainable".CSA has three pillars: increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing or removing greenhouse gas emissions from agriculture. CSA lists different actions to counter the future challenges for crops and plants. With respect to rising temperatures and heat stress, e.g., CSA recommends the production of heat tolerant crop varieties, mulching, water management, shade house, boundary trees and appropriate housing and spacing for cattle (Kideghesho ;2015). There are attempts to mainstream CSA into core government policies, expenditures and planning frameworks. In order for CSA policies to be effective, they must be able to contribute to broader economic growth, the sustainable development goals and poverty reduction. They must also be integrated with disaster risk management strategies, actions, and social safety net programmes.

CONCLUSION:

Climate change is posing significant challenges to agriculture, threatening food security, livelihoods, and the overall sustainability of the sector. Extreme weather events, rising temperatures, changes in precipitation patterns, and the spread of pests and diseases are all impacting crop and livestock production. To mitigate these adverse effects, a combination of adaptation and mitigation measures is essential (Joseph, 2015). Sustainable agricultural practices, access to climate information, rural infrastructure development, and financial support can help build resilience in the agriculture sector and secure food production in the face of a changing climate. Addressing climate change's impact on agriculture requires collective efforts from governments, farmers, researchers, and the private sector to ensure a sustainable and food-secure future Agriculture plays a significant role in climate change, both as a contributor to greenhouse gas emissions and as a sector vulnerable to the impacts of a changing climate. In this essay, we will delve into the various aspects of agriculture's role in climate change, including its contributions to greenhouse gas emissions, its susceptibility to climate impacts, and potential mitigation and adaptation strategies (Ekpo et al. ;2012).

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The Role of the Himachal Pradesh Horticulture Development Project to support small farmers and agro-entrepreneurs in Himachal Pradesh

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ABSTRACT

The Purpose of the Himachal Pradesh Horticulture Development Project for India is to support small farmers and agro-entrepreneurs in Himachal Pradesh, to increase the productivity, quality, and market access of selected horticulture commodities. This project consists of fourmajor components. **1) Production and Diversification** which aims to enhance horticultural competitiveness at the farm level by supporting access to knowledge, technology, and finance to increase long-term productivity and farm incomes in an environment marked by changing market patterns and increased climate variability.**2) Value Addition and Agro-enterprise Development** which aims to improve value realization at the farm level, promote investments in agribusiness, foster backward and forward linkages in the value chains for horticulture products, support supply chain infrastructure that prevents wastage and value erosion; and enable secondary and tertiary processing that create higher value for the produce. **3) Market Development** aims to provide an improved platform for market-related information and intelligence, expand market access through alternative marketing channels, enhance transparency in the price discovery process, and improve market infrastructure. **4) Project Management,** Monitoring, and Learning will ensure the effective implementation of the project activities and monitor and evaluate project implementation progress, outputs, and outcomes, building on implementation experience.

Keywords: *Horticulture, small farmer, agro-entrepreneurs, Market Development*

Introduction

Small farmers in Himachal Pradesh, like in many other parts of India, constitute a significant portion of the agricultural workforce. Understanding smallholding farmers, including their socio-economic characteristics, landholding size, income levels, and agricultural practices, is crucial for addressing their challenges and developing effective policies. In Himachal Pradesh, small farmers typically possess landholdings of less than 2 hectares, with many having less than 1 hectare due to the state's hilly terrain, resulting in land fragmentation. Given their limited land resources, these farmers often engage in subsistence farming, primarily growing crops for their consumption, which can lead to limited marketable surpluses. Consequently, they experience low and irregular income, highly dependent on agricultural activities, making them vulnerable to factors such as weather fluctuations and market volatility. Furthermore, agriculture in Himachal Pradesh is seasonal, with income concentrated around cropping seasons, contributing to limited income diversity, income inequality, and financial instability (Molina et al., 2018 Kitinoja, L. (2013); Masini, G., & Giordani, E. (2016); Pradhan et al, 2016).

Agricultural Practices

Agricultural practices among small farmers in Himachal Pradesh are characterized by a blend of traditional farming methods and crop diversity. These farmers predominantly rely on age-old techniques passed down through generations, emphasizing traditional and subsistence-oriented farming. Notably, crop diversity is a prominent feature of small-scale agriculture in the region. Farmers cultivate a wide range of crops, including staples like wheat, maize, and rice, alongside high-value horticultural crops such as apples, cherries, and various vegetables. However, these agricultural practices face significant challenges in areas where water availability is limited. Rain-fed agriculture is common, and many regions grapple with difficulties related to irrigation due to the absence of reliable sources of water (Manual 2019; Pathy, M. (2020); Hall et al, 2002; Ahmed et al., 2000).

Challenges in Traditional Agriculture:

1. Land Fragmentation:

The small size of landholdings due to fragmentation reduces the economic viability of traditional agriculture. It limits the adoption of modern agricultural practices and mechanization.

2. Limited Access to Credit:

Small farmers often struggle to access formal credit facilities, which hinders their ability to invest in farm inputs, technology, and infrastructure improvements.

3 Market Access:

Small farmers face challenges in accessing markets due to their remote locations and inadequate transportation infrastructure. This can result in low price realization and post-harvest losses.

4. Lack of Technology Adoption:

The adoption of modern agricultural technologies, such as improved seeds, fertilizers, and pest management practices, is limited among small farmers due to factors like lack of awareness, affordability, and access.

5. Climate Vulnerability:

Himachal Pradesh is prone to climate change impacts, including erratic weather patterns and natural disasters like landslides. Small farmers are particularly vulnerable to these climate-related risks.

6. Lack of Diversification:

Overdependence on a few crops can make small farmers susceptible to market price fluctuations and pest outbreaks. Diversification into high-value horticultural crops can be challenging due to resource constraints.

The Government of Himachal Pradesh (GoHP) is implementing a World Bank-funded project, namely the Himachal Pradesh Horticulture Development Project (HPHDP) with the objective "to support small farmers and agro-entrepreneurs in Himachal Pradesh to increase the productivity, quality, and market access of selected Horticulture commodities". HPHDP has four components (i) Horticulture production and diversification, (ii) Value addition and agro-enterprise development, (iii) Market development, and (iv) Project management. The Himachal Pradesh Horticulture Development Project (HPHDP) plays a significant role in supporting small farmers and agro-entrepreneurs in the state of Himachal Pradesh, India. This project aims to promote sustainable horticultural practices and enhance the livelihoods of rural communities, particularly those engaged in horticulture.Agri-Business Promotion Facility (ABPF) is a sub-component of Value addition and agroenterprise development which focuses on investment promotion in the Horticulture sector in the state. For this purpose, the project has established an Agri-Business Promotion Facility (ABPF) with a dedicated team of professionals to support interested entrepreneurs and existing businesses in value addition & agro-enterprise development (Ludwig-Ohm 2023; Dengerink et al 2020, Sharma, M. 2020). .

HPHDP supports small farmers and agro-entrepreneurs in Himachal Pradesh in the following ways:

1. Technical Support and Training:

HPHDP provides small farmers and agro-entrepreneurs with access to technical expertise and training programs. This includes workshops, seminars, and demonstrations on modern horticultural practices, such as improved planting techniques, pest and disease management, and post-harvest handling. These initiatives help farmers adopt best practices, increase their crop yields, and improve the quality of their produce.

2. Access to Quality Planting Material:

The project facilitates the distribution of high-quality planting material, including seeds and saplings of horticultural crops like apples, pears, cherries, and kiwis. Ensuring the availability of disease-resistant and high-yielding varieties is crucial for small farmers and agro-entrepreneurs to achieve better yields and income.

3. Infrastructure Development:

HPHDP invests in the development of essential infrastructure, such as irrigation systems, cold storage facilities, and packhouses. These facilities help in reducing post-harvest losses and preserving the quality of horticultural produce, enabling farmers to access markets with better-quality products.

4. Market Linkages:

The project assists farmers and agro-entrepreneurs in establishing market linkages. This includes connecting them with wholesalers, retailers, and export markets. By accessing broader markets, small-scale growers can improve their income and profitability.

5. Financial Support:

HPHDP often provides financial assistance to small farmers and agro-entrepreneurs through subsidies, grants, and credit programs. This financial support can help them invest in infrastructure, purchase inputs, and expand their horticultural operations.

6. Promotion of Organic Farming:

The project encourages the adoption of organic farming practices, which can fetch premium prices in domestic and international markets. Small farmers and agro-entrepreneurs are trained in organic farming techniques and supported in obtaining organic certifications.

7. Women and Youth Empowerment:

HPHDP recognizes the importance of empowering women and youth in agriculture. It provides training and support to women and young entrepreneurs interested in horticulture, helping them create sustainable livelihoods and become active participants in the agriculture sector.

8. Research and Innovation:

The project fosters research and innovation in horticulture, leading to the development of new technologies and practices that benefit small farmers and agro-entrepreneurs. This includes efforts to address challenges specific to Himachal Pradesh's unique agro-climatic conditions.

9. Sustainability and Environmental Conservation: HPHDP promotes sustainable horticultural practices that protect the environment and conserve natural resources. This aligns with the state's commitment to eco-friendly agriculture.

ADVANTAGES:

1. Diversified Income Sources:

HPHDP encourages farmers to diversify their crops, reducing dependence on a single crop and mitigating risks associated with crop failure. This diversification can lead to stable and increased income.

2. Improved Crop Quality and Yield:

The project provides farmers with training, modern farming techniques, and access to quality planting material. This helps in improving the quality and yield of horticultural produce, which can fetch higher prices in the market.

3. Market Access:

HPHDP focuses on improving market access for small farmers by facilitating linkages with markets, both within Himachal Pradesh and outside. This can lead to better prices for their produce.

4. Infrastructure Development:

The project often includes investments in infrastructure such as cold storage facilities, packhouses, and transportation, which can reduce post-harvest losses and increase the shelf life of horticultural products.

5. Skill Development:

HPHDP provides training and capacity-building programs to small farmers and agro-entrepreneurs. This empowers them with the knowledge and skills needed for efficient horticulture practices and agribusiness management.

6. Employment Generation:

Horticulture projects like HPHDP can create employment opportunities not only in farming but also in the processing, packaging, and marketing of horticultural products, benefiting both rural and urban populations (Booth, D., & Golooba-Mutebi, F. 2014; Sun et al, 2019; Berkers, E., & Geels, F. W. 2011; Arumugam, U., & Manida, M. 2023).

DISADVANTAGES:

1. Resource Constraints:

Limited funding and resources can hinder the comprehensive implementation of horticulture development projects. This may limit the scale and scope of support to farmers and agro-entrepreneurs.

2. Geographic Challenges:

Himachal Pradesh's terrain, with its steep slopes and remote areas, poses logistical challenges for reaching and assisting all small farmers, especially those in remote and inaccessible regions.

3. Climate Vulnerability:

Horticulture is highly sensitive to climate change, and Himachal Pradesh is not immune to extreme weather events. Unpredictable weather patterns can lead to crop losses and disrupt the livelihoods of farmers.

4. Market Volatility:
While improving market access is an advantage, it can also expose small farmers to market fluctuations and price volatility, potentially affecting their income.

5. Land Fragmentation:

In the hills of Himachal Pradesh, landholding sizes are often small and fragmented. This can limit the scalability of horticultural enterprises and impact their profitability.

6. Dependency on a Few Crops:

In some cases, horticulture development projects may focus on a few high-value crops, which can lead to over-dependence on these crops, making farmers vulnerable to market variations in those specific products (Singh et al., 2023; Mana et al., 20203)..

Its impact on supporting small farmers in the long run can be substantial and multifaceted:

1. Diversification of Income:

HPHDP encourages small farmers to diversify from traditional crops to high-value horticultural crops like apples, cherries, and vegetables. Over time, this diversification can significantly increase farmers' income as horticultural crops often yield higher returns per unit of land compared to traditional crops.

2. Technology Adoption:

The project provides small farmers with training and resources to adopt modern and sustainable horticultural practices. These technologies enhance crop quality, reduce post-harvest losses, and improve overall productivity, leading to increased income over the long term.

3. Market Access:

HPHDP helps small farmers access markets more effectively. Through initiatives like farmer-producer organizations (FPOs) and market linkages, small farmers can connect directly with buyers, reducing the role of intermediaries and ensuring better prices for their produce. This improved market access can result in more stable and higher incomes.

4. Capacity Building:

The project invests in the capacity building of small farmers and agro-entrepreneurs. By providing training on topics like crop management, post-harvest handling, and business skills, HPHDP equips farmers with the knowledge and skills needed to sustainably manage their agricultural enterprises.

5. Infrastructure Development:

HPHDP contributes to the development of essential infrastructure such as cold storage facilities, processing units, and transportation networks. This infrastructure enables small farmers to store their produce, add value to it, and transport it to markets more efficiently, extending their ability to generate income beyond the harvest season.

6. Access to Credit:

The project often facilitates access to credit and financial services for small farmers. Access to affordable credit can help farmers invest in their agricultural enterprises, purchase inputs, and expand their operations, leading to long-term income growth.

7. Empowerment of Women:

HPHDP often promotes the participation of women in horticulture-related activities. This empowerment can lead to increased household income and economic independence for women, positively impacting the family's long-term economic stability.

8. Environmental Sustainability:

By promoting sustainable agricultural practices, HPHDP contributes to the preservation of natural resources. This ensures that small farmers can continue to generate income from their land over the long run without depleting or degrading the environment.

9. Resilience to Climate

Change: As horticultural crops can be more resilient to climate change compared to traditional crops, the project helps small farmers adapt to changing climate conditions, reducing the risk of crop failure and income loss in the long term.

10. Policy Influence:

The successes and lessons learned from HPHDP can influence state and national horticulture policies and strategies, creating an enabling environment for long-term support to small farmers and agro-entrepreneurs not only in Himachal Pradesh but also in other regions.

Projects like the Himachal Pradesh Horticulture Development Project (HPHDP) can be effective in supporting small farmers and agro-entrepreneurs in the state if well-implemented and if they address the specific challenges and needs of the target groups. However, to continually improve the effectiveness of such projects, several strategies can be considered:

1.Customization and Targeting:

Tailor project interventions to the unique needs of different regions within Himachal Pradesh, considering variations in climate, topography, and crop suitability.

Implement a targeted approach that focuses on vulnerable or marginalized groups of small farmers and agro-entrepreneurs, such as women, tribal communities, and landless laborers.

2.Capacity Building:

Invest in comprehensive training and capacity-building programs for small farmers and agro-entrepreneurs. These programs should cover modern agricultural practices, financial literacy, business management, and marketing skills.Foster a culture of continuous learning and knowledge sharing through farmer field schools, demonstration plots, and extension services.

3.Access to Finance:

Facilitate access to credit and financial services, including microfinance options, to help small farmers invest in their agricultural enterprises, purchase quality inputs, and manage risks effectively.

Encourage the establishment of community-based savings and credit groups to promote financial inclusion at the grassroots level.

4.Market Linkages:

Strengthen and expand market linkages for small farmers by connecting them with agribusinesses, cooperatives, and value chain actors.

Promote the establishment of farmer-producer organizations (FPOs) to collectively negotiate prices, improve bargaining power, and access larger markets.

5.Infrastructure Development:

Continue investing in critical infrastructure such as cold storage facilities, processing units, and transportation networks to reduce post-harvest losses and enhance the value chain.Ensure that infrastructure development is sustainable and environmentally friendly.

6. Technology Adoption:

Promote the adoption of modern agricultural technologies, including precision farming, organic farming, and ICT-based tools, to increase productivity, reduce input costs, and improve product quality.Provide access to affordable and locally relevant technologies and equipment.

7Climate Resilience:

Incorporate climate-smart agriculture practices into the project, helping small farmers adapt to changing climate conditions and reduce vulnerabilities to extreme weather events.Encourage the use of drought-resistant and climate-resilient crop varieties.

8.Gender Inclusion:

Ensure that project activities are gender-inclusive by promoting the active participation of women in all aspects of horticulture, including decision-making, training, and leadership roles. Address gender-specific challenges and provide support for women-led enterprises.

9.Monitoring and Evaluation:

Establish a robust monitoring and evaluation framework to track the project's progress, measure impact, and make necessary adjustments. Engage in regular feedback mechanisms with beneficiaries to gather insights and incorporate their suggestions.

10.Policy Advocacy:

Advocate for policy changes at the state and national levels to create a conducive environment for horticultural development and small-scale entrepreneurship.Collaborate with government agencies to align project objectives with existing policies and programs.

11.Sustainability and Exit Strategies:

Develop exit strategies to ensure that project benefits continue even after project funding ends.Encourage the establishment of self-sustaining mechanisms, such as producer cooperatives and value chain partnerships.

12.Research and Innovation:

Support research and innovation in horticulture to identify new crop varieties, pest control methods, and farming practices that can enhance productivity and sustainability. Promote the adoption of innovative and efficient agricultural technologies.

By implementing these strategies, projects like HPHDP can become even more effective in supporting small farmers and agro-en

FIG 1 Photograph of Market Yard Palampur (Work Completed)

trepreneurs in Himachal Pradesh, leading to sustainable livelihoods, increased incomes, and overall rural development in the state.

STUDIES DONE ON COMPONENT C:MARKET DEVELOPMENT

Under the Himachal Pradesh Development Project funded by the World Bank. The focus of this component of the project has been determined to improve market infrastructure upgrade wholesale markets and support the setting up of Economic Market Information and Intelligence Services (EMIC).Market Development would be supported by the development of basic infrastructure that promotes improved handling of commodities, improved hygiene, and improved price dissemination. The infrastructure developed under the project includes auction platforms, internal roads, toilets, parking, loading-unloading platforms, and ramps. Fence etc. Under this project, the Upgradation,Strengthening, and construction of new market yards have been done at Palampur, Kangni, Paonta, Shatt, Parwanoo, Parala,Bandrol,Mehandali, and Shilaroo (Shatt, Parwanoo, Parala, Bandrol, Mehandali, and Shilaroo Nweze et al., 2023); Reis et al, 2023).

FIG 2 Photograph of Kangni Market Yard (Work Completed)

Summary & Conclusion:

Small farmers in Himachal Pradesh face a range of socio-economic challenges, including small landholdings, low income, and limited access to resources and technology. Addressing these challenges requires targeted interventions such as access to credit, extension services, modern agricultural practices, and market linkages. Promoting sustainable and income-enhancing agricultural practices, especially in horticulture, can contribute to improving the livelihoods of small farmers in the state.

Himachal Pradesh Horticulture

Development Project has the potential to bring about significant and sustained positive impacts on small farmers and agro-entrepreneurs in the state. By focusing on diversification, technology adoption, market access, capacity building, and sustainability, the project can contribute to the long-term economic well-being of small farmers, enhancing their resilience and livelihoods in the face of various challenges.

Project plays a crucial role in supporting small farmers and agro-entrepreneurs by promoting diversification, improving crop quality, and enhancing market access. However, it also faces challenges related to resource constraints, climate vulnerability, and market fluctuations that need to be addressed to ensure sustainable development and income improvement for the targeted beneficiaries. It serves as a vital catalyst for the growth of horticulture in Himachal Pradesh by offering technical knowledge, infrastructure, financial assistance, and market access to small farmers and agro-entrepreneurs. Through these initiatives, HPHDP contributes to improving the livelihoods of rural communities and enhancing the state's overall agricultural productivity and sustainability.

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DNA MODIFYING ENZYMES USED IN BIOTECHNOLOGY –LATEST UPDATES

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ABSTRACT

With the widespread adoption of molecular cloning as a routine laboratory technique, there is now a vast array of enzyme sources available from manufacturers for the generation and manipulation of nucleic acids. However, for those new to the field, the task of selecting the most suitable enzyme for a specific task can be daunting. This review aims to provide readers with valuable insights into the function and specificities of various sources of polymerases, ligases, nucleases, phosphatases, methylases, and topoisomerases commonly used in molecular cloning. We offer a comprehensive description of the most frequently utilized enzymes within each group, along with an explanation of their properties and mechanisms of action. By highlighting the key requirements for each enzymatic activity and addressing their limitations, our objective is to assist readers in making informed decisions when selecting the appropriate enzymatic source and determining the optimal experimental conditions for their molecular cloning experiments.
Key words: molecular cloning, polymerases, ligases, nucleases, phosphatases, methylases, and topoisomerases

KEYWORDS: Molecular Cloning, Polymerases, Ligases, Nucleases, Phosphatases, Methylases, And Topoisomerases

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INTRODUCTION

Molecular cloning involves the use of nucleic acids, which can be either natural or synthetic and vary in length from a few to several thousand nucleotides.

These nucleic acids can be manipulated extensively to acquire specific characteristics and properties, including propagation, ligation, digestion, and the addition of modifying groups such as phosphate or methyl groups.

These modifications are catalyzed by various enzymes, including polymerases, ligases, nucleases, phosphatases, and methylases. In this review, we aim to provide a comprehensive description of the main enzymes in each group, including their properties and mechanisms of action.

According to T. A. Brown here are 4 main enzyme (Brown, 2020).

1) **DNA polymerases**
2) **Nucleases**
3) **Ligases**
4) **End-modification enzymes**

1) DNAPOLYMERASES

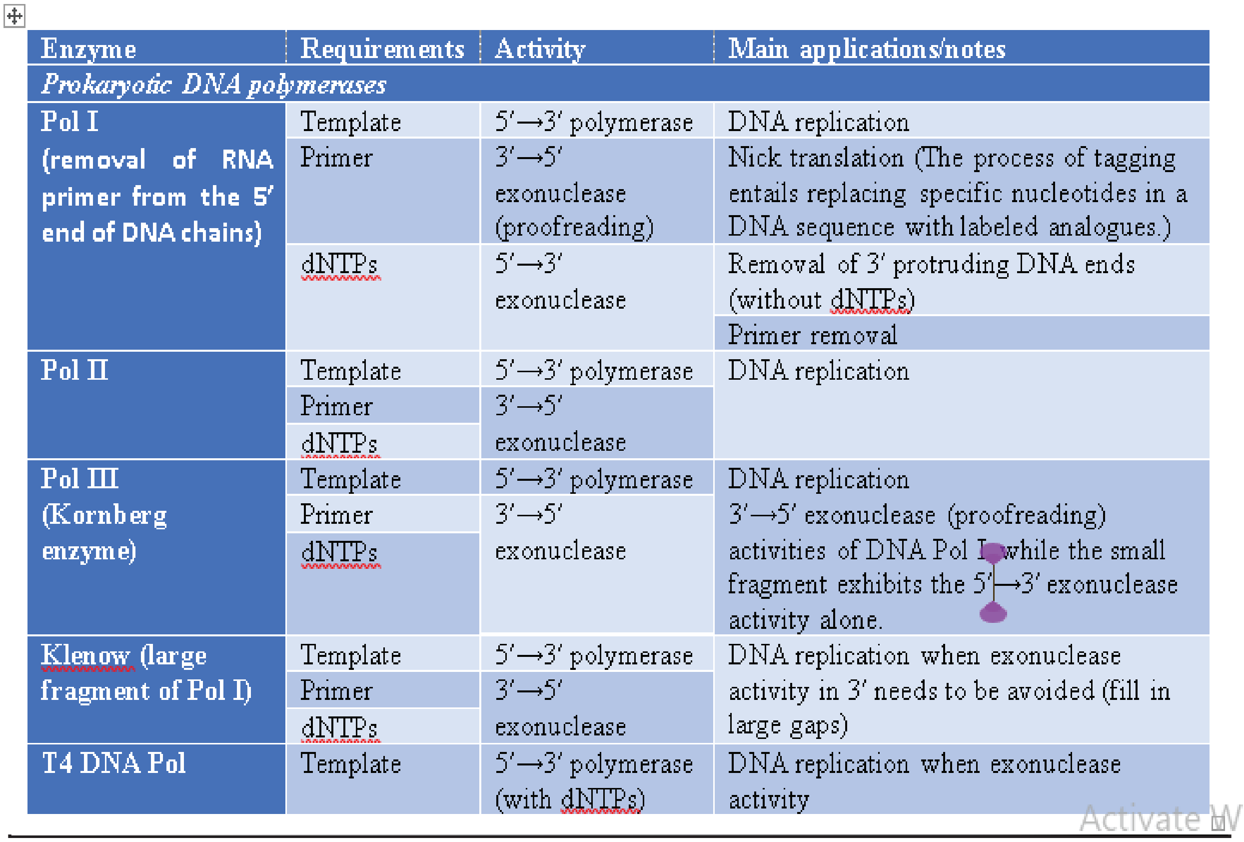
The enzymes responsible for synthesizing new polynucleotides that are complementary to an existing DNA or RNA template are commonly referred to as DNA polymerases. These enzymes are capable of adding nucleotides solely to the 3'-OH end of a pre-existing primer that contains a 5'-phosphate group. In order to initiate DNA synthesis, short stretches of RNA that are complementary to approximately 10 nucleotides of DNA at the 5' end of the molecule are required. These RNA primers are synthesized by an RNA polymerase known as primase.

THE T4 BACTERIOPHAGE polymerase, also known as T4 DNA polymerase, requires both a template and a primer to exhibit two distinct activities. In the absence of deoxynucleoside triphosphates (dNTPs), it functions as a 3′→5′ (reverse) exonuclease. Conversely, in the presence of dNTPs, it acts as a 5′→3′ polymerase. Unlike *E. coli* DNA Pol I, *T4 DNA Pol* does not possess a 5′→3′ exonuclease activity (Ritié and Perbal, 2008). As a result, T4 DNA Pol can be utilized in lieu of Klenow for filling in 5′-protruding ends of DNA fragments, nick translation, or labeling 3′ ends of double-stranded DNA. The T4 DNA Pol exonuclease rate is approximately 40 bases per minute on double-stranded DNA and about 4,000 bases on single-stranded DNA. Under standardized conditions, the T4 DNA Pol polymerization rate reaches 15,000 nucleotides per minute.

Richardson *et al.* (Tabor and Richardson, 1989) have reported on a chemically modified bacteriophage T7 DNA polymerase that is highly suitable for DNA sequencing. This modified T7 DNA polymerase has an impressive polymerization rate of over 300 nucleotides per second, making it more than 70 times faster than the AMV reverse transcriptase **(Avian Myeloblastosis Virus (AMV**) Reverse Transcriptase is an RNA-directed DNA polymerase.

DNA synthesis from either RNA or ssDNA is possible with AMV and it is ideal for RT-PCR, cDNA synthesis, and RNA sequencing By conducting **in-vitro mutagenesis** on the corresponding nucleotides in the T7 gene 5, the exonuclease activity has been completely eliminated, resulting in a significant increase in polymerase efficiency (9-fold) and spontaneous mutation rate (14-fold). This mutant T7 polymerase/thioredoxin complex, commercially known as sequenase **(United States Biochemical Corporation),** is widely used for DNA sequencing due to its exceptional efficiency and ability to incorporate nucleotide analogs. These analogs, such as 5′-(α-thio)-dNTPs, dc7-

Table-1 Main DNA polymerases used in molecular biology (Rittié and Perbal, 2008).



Enzyme	Requirements	Activity	Main applications/notes
Prokaryotic DNA polymerases			
Pol I (removal of RNA primer from the 5′ end of DNA chains)	Template	5′→3′ polymerase	DNA replication
	Primer	3′→5′ exonuclease (proofreading)	Nick translation (The process of tagging entails replacing specific nucleotides in a DNA sequence with labeled analogues.)
	dNTPs	5′→3′ exonuclease	Removal of 3′ protruding DNA ends (without dNTPs)
			Primer removal
Pol II	Template	5′→3′ polymerase	DNA replication
	Primer	3′→5′ exonuclease	
	dNTPs		
Pol III (Kornberg enzyme)	Template	5′→3′ polymerase	DNA replication
	Primer	3′→5′ exonuclease	3′→5′ exonuclease (proofreading) activities of DNA Pol I while the small fragment exhibits the 5′→3′ exonuclease activity alone.
	dNTPs		
Klenow (large fragment of Pol I)	Template	5′→3′ polymerase	DNA replication when exonuclease activity in 3′ needs to be avoided (fill in large gaps)
	Primer	3′→5′ exonuclease	
	dNTPs		
T4 DNA Pol	Template	5′→3′ polymerase (with dNTPs)	DNA replication when exonuclease activity

Figure 1 Function of DNA polymerase

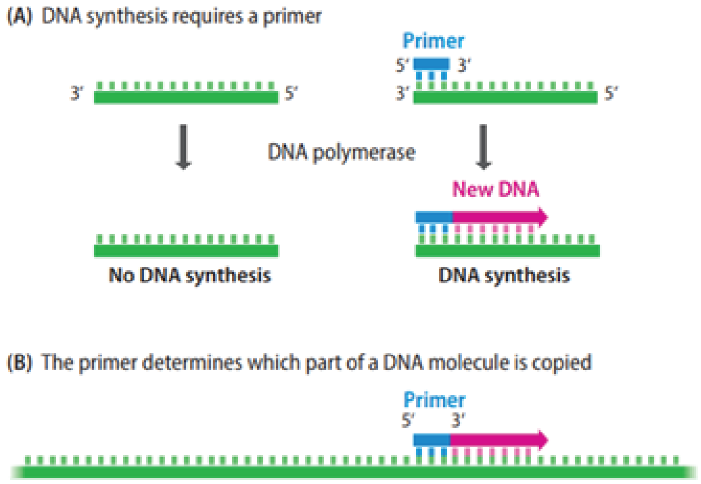


Figure 2 : Mechanism of DNA synthesis

GTP, or dITP, are employed to improve the resolution of DNA sequencing gels and prevent gel compression caused by base pairing. Taq polymerase was purified by Chien et al. in 1976 from Thermophilus aquaticus, a bacterium that was discovered in 1969 in the Great Fountain region of Yellowstone National Park by Brock and Freeze. *T. aquaticus* is able to thrive at temperatures of 70°C and can survive at even higher temperatures of up to 80°C. The half-life of Taq polymerase is 40 minutes at 95°C and 5 minutes at 100°C, making it suitable for use in the polymerase chain reaction (PCR). To achieve optimal activity, Taq polymerase requires the presence of Mg2+ and a temperature of 80°C. Although Taq polymerase does not possess 3′→5′ exonuclease activity, which is responsible for proofreading and error correction, it is still considered a low fidelity enzyme with an error rate ranging from $1 \times 10-4$ to $2 \times 10-5$ errors per base pair, depending on the specific experimental conditions.

However, it is worth noting that this error rate still corresponds to a relatively high level of accuracy, as approximately 45,000 nucleotides can be incorporated into newly synthesized DNA strands before an error occurs. Similar to other DNA polymerases that lack 3′→5′ exonuclease activity, Taq polymerase exhibits a deoxynucleotidyl transferase activity, which involves the addition of a few adenine residues at the 3′-end of PCR products. Thermostable DNA polymerases with proofreading activity are enzymes isolated from thermophilic organisms that exhibit 3′→5′ exonuclease activity, which increases fidelity. Among them, the DNA polymerase from the archaeobacterium *Pyrococcus furiosus (Pfu)* has an error rate (1.6×10^{-6}) 10-fold lower than that of Taq polymerase and can be purchased from numerous providers. ***Pow polymerase***, isolated from *Pyrococcus woesei,* has a half-life greater than 2 hours at 100°C and a very low error rate of $7.4 \times 10^{-7.}$ Pow polymerase provides high PCR yields only for templates shorter than 3.5 kb.

To circumvent PCR product size limitation, a mixture of Taq and Pow DNA polymerases has been commercialized by Roche Molecular Chemicals (under the name "Expand high fidelity"). This system allows amplification and cloning of long stretches of DNA (20–35 kb) and represents a unique tool for analyzing and sequencing large eukaryotic genes or introducing large DNA fragments in lambda phages or cosmid vectors.

Vent polymerase, also known as Tli polymerase since isolated from Thermococcus litoralis, has an error rate comprised between that of Taq and Pfu. Vent polymerase has a half-life of 7 hours at 95°C and is marketed by New England Biolabs, together with a modified version that lacks exonuclease (proofreading) activity. Two DNA polymerases (Pol I and II) that exhibit 3′→5′ exonuclease proofreading activity were also isolated from Pyrococcus abyssi *(Gueguen et al., 2001; Zappa et al., 2001).* Pol I DNA polymerase from P. abyssi (Pab), marketed by Qbiogen as "is DNA Polymerase", has an error rate (0.66×10^{-6}) similar to that of Pfu.

However, Pab is more thermostable than Pfu or Taq (Pab has a half-life of 5 hours at 100°C), making it very useful for conducting PCR reactions that involve high-temperature incubations.

2. REVERSE TRANSCRIPTASE

Which is an RNA-dependent DNA polymerase and so makes DNA copies of RNA rather than DNA templates. Reverse transcriptase are involved in the replication cycles of retroviruses. Including the human immunodeficiency viruses, which have RNA genomes that are copied into DNA after infection of the host. In the test tube, a reverse transcriptase can be used to make DNA copies of mRNA molecules. These copies are called complementary DNAs (cDNAs). Their synthesis is important in some types of gene cloning and in techniques used to map the regions of a genome that specify particular mRNAs. Because RTs are deprived of 3′→5′ exonuclease (proofreading) activity, they have much lower fidelity than DNA-dependent DNA polymerases. For instance, HIV RT has an error rate of 1 mutation per 1,500 nucleotides, whereas RT of avian and murine origin generate 1 mutation per 17,000 and 30,000 nucleotides, respectively. The AMV/MAV RT is comprised of two subunits, α and β, which are structurally related. The α subunit weighs 65 kDa and the β subunit weighs 95 kDa. The enzyme's α subunit provides both RT and RNase H activities. The RT activity requires the presence of a primer and a template, as noted by Leis et al. (1983) and Verma (1977). The AMV/MAV RT is commonly used to replicate total messenger RNAs using polydT or random primers.(Verma, 1977). The RNase H activity is produced by the proteolytic cleavage of the α subunit and is associated with a 24 kDa fragment. RNase H is a processive exoribonuclease that specifically degrades RNA strands in RNA-DNA hybrids in either the 5′→3′ or 3′→5′ directions.

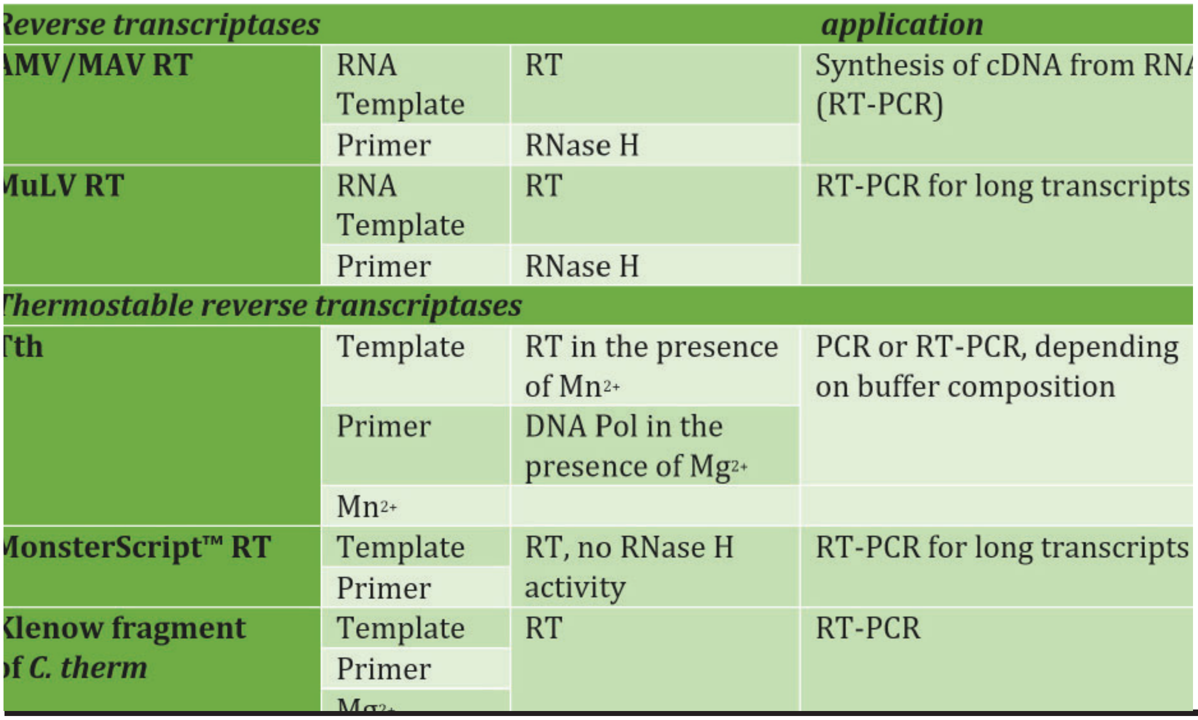
Uses

1)in Reverse Transcription Polymerase Chain Reaction (RT-PCR).2)

3. NUCLEASES

Nucleases are a class of enzymes that possess the ability to cleave, shorten, or degrade nucleic

ble 2 *Reverse transcriptases* (Rittié and Perbal, 2008)



everse transcriptases			***application***
MV/MAV RT	RNA Template	RT	Synthesis of cDNA from RN (RT-PCR)
	Primer	RNase H	
uLV RT	RNA Template	RT	RT-PCR for long transcripts
	Primer	RNase H	
hermostable reverse transcriptases			
th	Template	RT in the presence of Mn^{2+}	PCR or RT-PCR, depending on buffer composition
	Primer	DNA Pol in the presence of Mg^{2+}	
	Mn^{2+}		
onsterScript™ RT	Template	RT, no RNase H activity	RT-PCR for long transcripts
	Primer		
lenow fragment f *C. therm*	Template	RT	RT-PCR
	Primer		
	Mg^{2+}		

Reverse transcriptases			**application**
AMV/ MAV RT	RNA Template	RT	Synthesis of cDNA from RNA (RT-PCR)
	Primer	RNase H	
MuLV RT	RNA Template	RT	RT-PCR for long transcripts
	Primer	RNase H	
Thermostable reverse transcriptases			
Tth	Template	RT in the presence of Mn2+	PCR or RT-PCR, depending on buffer composition
	Primer Mn2+	DNA Pol in the presence of Mg2+	
Monster-Script™ RT	Template, Primer	RT, no RNase H activity	RT-PCR for long transcripts
Klenow fragment of *C. therm*	Template, Primer, Mg^{2+}	RT	RT-PCR

acid molecules. There are two distinct types of nuclease enzymes: exonucleases and endonucleases.
Which degrade DNA molecules by breaking the phosphodiester bonds that link one nucleotide to the next (Figure .3.)
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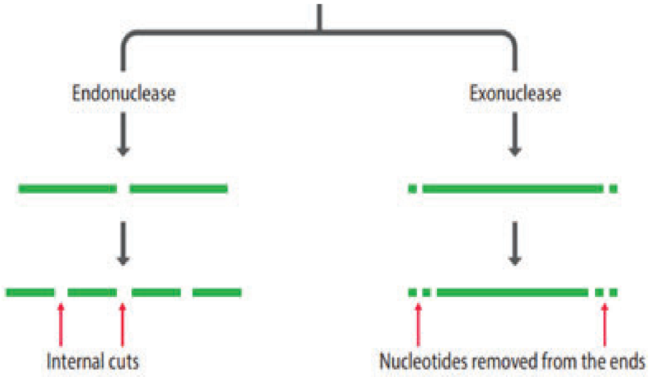


Nucleases are enzymes that hydrolyze phosphodiester bonds in the backbone of nucleic acids.

These enzymes can be classified into two main categories based on their mode of action.

Exonucleases act on the ends of nucleic acid molecules, while endonucleases cleave nucleic acids internally.

Deoxyribonucleases specifically cleave DNA and produce nicks, which are points in a double-stranded DNA molecule where there is no phosphodiester bond between adjacent nucleotides of one strand.

These nicks can occur due to damage or the action of enzymes. On the other hand, ribonucleases cleave RNA. Nucleases play a dual role for molecular biologists.

On one hand, they pose a significant threat to the integrity of nucleic acids. On the other hand, they are invaluable tools for cutting and manipulating nucleic acids for cloning purposes.

S1 nuclease (EC 3.1.30.1) is a valuable tool for measuring the extent of hybridization between DNA and RNA, probing duplex DNA regions, and removing single-stranded DNA of protruding ends generated by restriction enzymes. This enzyme is purified from ***Aspergillus oryzae*** and degrades RNA or single-stranded DNA into 5' mononucleotides, while not degrading duplex DNA or RNA-DNA hybrids in their native conformation. S1 nuclease is a 32 kDa metalloprotein **(Vogt 1973)** that requires Zn2+ for activity. Although Co2+ and Hg2+ can replace Zn2+, they are less effective as cofactors. The optimal activity of S1 nuclease is achieved at pH 4.0-4.3, with a 50% reduction of activity observed at pH 4.9, and the enzyme becoming inactive at pH > 6.0.

Chelating agents such as EDTA and citrate, or low concentrations of sodium phosphate (as low as 10 mM), strongly inhibit S1 nuclease. However, this nuclease is resistant to denaturing agents such as urea, SDS, or formamide. S1 nuclease exhibits a hydrolytic activity that is five times more rapid on single-stranded DNA compared to RNA, and an astonishing 75,000 times faster on double-stranded DNA. The minimal occurrence of strand breaks induced by S1 nuclease in duplex DNA can be further diminished by employing a high salt concentration, specifically 0.2 M. S1 nuclease demonstrates its enzymatic efficacy at S1 sensitive sites that arise from negative supercoiling of the helical DNA structure, UV irradiation, or depurination (Wiegand, Godson and Radding, 1975; Kroeker, Kowalski and Laskowski, 1976).

APPLICATION OF S1 NUCLEASE

1) For specific removal of single portions of duplex DNA, RNA/DNA hybrids, or RNA molecules.

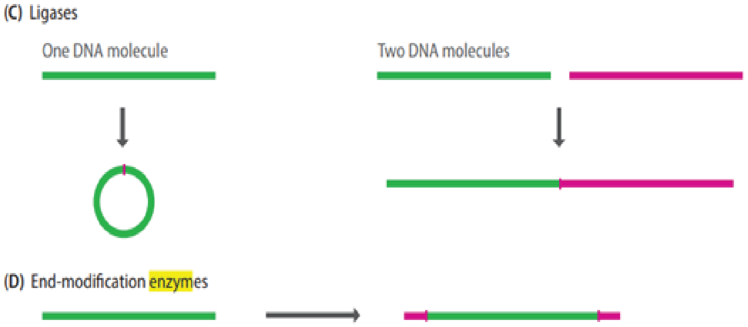
2) mapping of spliced RNA molecules, isolation of duplex regions in single stranded viral genomes.
3) probing strand breaks in duplex DNA molecules.
4) mapping of the genomic regions involved in interactions with DNA binding proteins.

MUNG BEAN NUCLEASE is a highly specific single-stranded DNA and RNA endonuclease that has been purified from mung bean sprouts. This enzyme produces mono- and oligonucleotides with 5'-phosphate terminations. To achieve maximum activity and stability, mung bean nuclease requires the presence of Zn2+ and a reducing agent such as cysteine. However, it is important to note that high salt concentrations, specifically in the range of 200-400 mM NaCl, can inhibit its activity by 80-90%. To enhance the stability of mung bean nuclease and prevent its adhesion to surfaces, the addition of Triton X-100 at a low concentration of 0.001% w/v, particularly when used at less than 50 U/μl, can be beneficial. Mung bean nuclease can be employed similarly to nuclease S1 for the purpose of eliminating protruding ends in duplex DNA or for transcription promoter mapping (Kroeker, Kowalski and Laskowski, 1976).

4. LIGASES

Ligases, join DNA molecules together by synthesizing phosphodiester bonds between nucleotides at the ends of two different molecules or at the two ends of a single molecule. The enzyme used most often in experiments is T4 DNA ligase, which is purified from E. coli cells infected with bacteriophage T4.

DNA ligase is an important cellular enzyme, as its function is to repair broken phosphodiester bonds that may occur at random or as a consequence of DNA replication or recombination.



In genetic engineering it is used to seal dis-

Enzyme	Require-ments	Activity	Main applica-tions/notes
DNA ligases			
T4-DNA Ligase	Mg2+, /ATP	Connects blunt and cohesive ends in duplex DNA, RNA or DNA/ RNA hybrids	Most frequently used for cloning
E. Coli DNA ligase	Mg2+ / NAD+	Connects preferentially cohesive double-stranded DNA ends, active on blunt ends DNA in the presence of Ficoll or polyethylene glycol	Ligation when blunt end or RNA/ DNA ligation needs to be avoided
Thermostable DNA ligases (various sources)		Ligation at high temperature	Not a substitute for T4 or E. Coli ligases, but used for specific techniques like LCR.
RNA ligases			
T4 RNA ligase 1	ATP	Ligates single stranded nucleic acids and polynucleotides to RNA molecules	RNA labeling, primer extension
T4 RNA ligase 2 (T4 Rnl-2)	ATP	Ligates double-stranded RNA or connects dsRNA to dsDNA	Repair nicks in dsRNA
Truncated T4 RNL2		Ligates pre-adenylated 5′ end of DNA or RNA to 3′ end of RNA molecules	Optimized linker ligation for cloning of microRNAs

In cellular biology, DNA ligases play a crucial role in the joining of Okazaki fragments during replication, as well as in the final stage of the DNA repair process. In molecular biology, DNA ligases are utilized to connect DNA fragments with either blunt or sticky ends, which are generated by restriction enzyme digestion, to add linkers or adaptors to DNA, or to repair nicks.

The operation of DNA ligases involves a three-step reaction. The first step involves the creation of a ligase-adenylate intermediate, in which a phosphoamide bond is formed between a lysine residue and one AMP molecule of the enzyme cofactor (ATP or NAD$^+$). The second step involves the transfer of the AMP to the 5′-phosphate end of the DNA nick to form a DNA-adenylate (AppDNA). Finally, a nucleophilic attack from the 3′ end of the DNA nick directed to the AppDNA results in the joining of the two polynucleotides and the release of AMP. Bacterial DNA ligases utilize NAD+ as a cofactor, while DNA ligases from eukaryotes, viruses, and bacteriophages use ATP. The most commonly used ligase in molecular biology is the bacteriophage T4 DNA ligase, which is a 68 kDa monomer that requires Mg^{2+} and ATP as cofactors. T4 DNA ligase is capable of connecting blunt and cohesive ends, as well as repairing single-stranded nicks in duplex DNA, RNA, or DNA/RNA hybrids.

The *E. Coli* DNA ligase exhibits a preference for cohesive double-stranded DNA ends. However, it can also function on blunt ends DNA in the presence of Ficoll or polyethylene glycol. Hybrids such as DNA-RNA or RNA-RNA are not efficiently formed by E. Coli DNA ligase. This characteristic can be advantageous when double-stranded DNA ligation is desired and blunt end ligation needs to be avoided.

Thermostable DNA ligases possess the capability to conduct ligation of duplex molecules and repair single stranded nicks within a temperature range of 45 to 80°C. These ligases exhibit a high level of specificity and are particularly suitable for applications requiring stringent ligations. They are derived from various sources, including Thermus thermophilus.

Thermostable DNA ligases are typically not employed as replacements for T4 or E. Coli DNA ligases, but rather find utility in highly specific methodologies such as Ligase Chain Reaction (LCR).

LCR serves as a technique for identifying single base mutations, wherein a primer is synthesized in two segments that encompass both ends of a potential mutation. The thermostable ligase will solely join the two segments if they precisely match the template sequence. Subsequent PCR reactions will only amplify if the primer is ligated.

RNA ligases (EC 6.5.1.3) are enzymes that facilitate the ATP-dependent synthesis of phosphodiester bonds between the 5′-phosphate and 3′-OH termini of single stranded RNA or DNA molecules. Their primary function in cellular processes is to repair damaged RNA molecules. Similar to DNA ligases, RNA ligases undergo a three-step reaction process (Silber et al. 1972; Sugino et al. 1977). Initially, the RNA ligase reacts with ATP to form a covalent intermediate known as ligase-(lysyl-N)-AMP, along with the release of pyrophosphate. Subsequently, the AMP component of the ligase adenylate is transferred to the 5′-phosphate end of the RNA, resulting in the formation of an RNA-adenylate intermediate (AppRNA). Finally, the 3′-OH end of the RNA undergoes a nucleophilic attack on the AppRNA, leading to the creation of a phosphodiester bond that effectively seals the two RNA ends together.

5) END-MODIFICATION ENZYMES

End-modification enzymes, which make changes to the ends of DNA molecules

There are numerous enzymes that modify DNA molecules by addition or removal of specific chemical groups.

A). ALKALINE PHOSPHATASE

- This enzyme removes phosphate group at the 5’ terminus of a DNA molecule.

The enzymes alkaline phosphatase, polynucleotide kinase, and terminal transferase play crucial roles in DNA manipulation by acting on the termini of DNA molecules. The alkaline phosphatase and polynucleotide kinase enzymes are responsible for the removal or addition of phosphate groups.

Bacterial alkaline phosphatase, along with its similar counterpart calf intestinal alkaline phosphatase, specifically removes phosphate groups from the 5 ends of DNA, resulting in a 5-OH group. This enzymatic activity is particularly useful in preventing unwanted ligation of DNA molecules, which can be problematic in certain cloning procedures. Additionally, it is employed prior to the addition of radioactive phosphate to the 5 ends of DNAs by polynucleotide kinase.

B) TERMINAL TRANSFERASE

Terminal deoxynucleotidyl transferase (TdT) is a DNA polymerase that was first isolated from calf thymus by Krakow et al. in 1962 (Krakow, Coutsogeorgopoulos and Canellakis, 1962). This enzyme catalyzes the addition of a homopolymer tail to the 3′-OH ends of DNA in a template-independent manner. TdT is commonly used in molecular biology for labeling DNA 3′

ends with modified nucleotides, such as ddNTP, DIG-dUTP, or radiolabeled nucleotides, as well as for primer extension and DNA sequencing. Additionally, TdT is utilized in the TUNEL (TdT dUTP Nick End Labeling) assay to demonstrate apoptosis, as described by Gavrieli et al. in 1992 *(Gavrieli, Sherman and Ben-Sasson, 1992; Ashley, Potts and Olorunniji, 2023).*

Terminal deoxynucleotidyl transferase (TdT) is an enzyme that facilitates the incorporation of arbitrary nucleotides onto single-stranded DNA without the need for a template. This unique characteristic has made TdT a valuable tool in both biotechnology and clinical applications. One particularly intriguing application is the synthesis of long de novo DNA molecules through TdT-mediated iterative incorporation of a reversibly blocked nucleotide at the 3' end, followed by deblocking.

However, the wild-type (WT) TdT is not well-suited for the incorporation of modified nucleotides at the 3' end, and the engineering of TdT is hindered by its marginal stability and limited presence in mesophilic organisms. (Chua et al., 2020).

c) Polynucleotide kinase is an enzyme that catalyzes the addition of a phosphate group to the 5' terminus of a DNA molecule.

The T4 polynucleotide kinase (Pnk) is not only a valuable research tool, but also represents a group of bifunctional enzymes that possess both 5′-kinase and 3′-phosphatase activities, which are crucial in the repair of RNA and DNA. (Wang, Lima and Shuman, 2002).

6. Exonucleases are enzymes capable of breaking phosphodiester bonds at the terminal end of a DNA molecule.

9. An example of an exonuclease is Bal31, which is known for its ability to remove nucleotides from both sides of a double-stranded DNA molecule. Bal31 is purified from the bacterium Alteromonas espenjiana.

10. Exonuclease III

- It degrades just one strand of double stranded DNA molecule and leave single stranded DNA as the product.

1) Bal 31
2) exonuclease III (exonucleases),
3) deoxyribonuclease I (DNase I)

Nuclease Bal 31 is a complex enzyme.

Its primary activity is a fast-acting 3' exonuclease, which is coupled with a slow-acting endonuclease. When Bal 31 is present at a high concentration these activities effectively shorten DNA molecules from both termini.

1) Exonuclease III is a 3' exonuclease that generates molecules with protruding 5' termini.
2) DNase I cuts either single-stranded or double-stranded DNA at essentially random sites.
3) Nuclease S1 is specific for single-stranded RNA or DNA.

11. 2). Endonuclease

- It is able to break internal phosphodiester bond of the DNA molecule.

12. S1 endonulease

- It cleaves only single strand.
- It is purified from the fungus Aspergillus oryzae

13. Deoxyribonuclease 1 (Dnase 1)

- It cleaves both single stranded and double stranded DNA.
- It is purified from cow pancreas. This enzyme is non-specific.

14. RNase A :

It digests ssRNA at 3' terminus. • RNase H : It digests RNA on RNA-DNA heteroduplex.

15. SPECIAL CLASS OF ENDONUCLEASE

a) Restriction Endonuclease

This type of enzymes cleaves specific recognition site on double stranded DNA.

RESTRICTION ENDONUCLEASES

1) Also called restriction enzymes
2) 1962: "molecular scissors" discovered in in bacteria
3) E. coli bacteria have an enzymatic im-

mune system that recognizes and destroys foreign DNA

4) 3,000 enzymes have been identified, around 200 have unique properties, many are purified and available commercially.

there are two different kinds of restriction enzymes:

(1) Exonucleases catalyses hydrolysis of terminal nucleotides from the end of DNA or RNA molecule either 5'to 3' direction or 3' to 5' direction. Example: exonuclease I, exonuclease II etc.

(2) Endonucleases can recognize specific base sequence (restriction site) within DNA or RNA molecule and cleave internal phosphodiester bonds within a DNA molecule.

Example: EcoRI, Hind III, BamHI etc.

Restriction Endonuclease Nomenclature:

Restriction endonucleases are named according to the organism in which they were discovered, using a system of letters and numbers. For example, HindIII (pronounced "hindee-three") was discovered in Haemophilus influenza (strain d). The Roman numerals are used to identify specific enzymes from bacteria that contain multiple restriction enzymes indicating the order in which restriction enzymes were discovered in a particular strain.

Named for bacterial genus, species, strain, and type

Example: EcoR1

Genus:Escherichia

Species: coli

Strain: R

Order discovered: 1

Enzymes recognize specific 4-8 bp sequences which are palindromic.

Uses of restriction enzymes

- RFLP analysis (Restriction Fragment Length Polymorphism)
- DNA sequencing
- DNA storage – libraries
- Transformation
- Large scale analysis – gene chips 2-1.4

CLASSIFICATION OF RESTRICTION ENDONUCLEASES:

There are three major classes of restriction endonucleases based on the types of sequences recognized, the nature of the cut made in the DNA, and the enzyme structure:

- Type I restriction enzymes
- Type II restriction enzymes
- Type III restriction enzymes

2-1.4.1 TYPE I RESTRICTION ENZYMES:

- These enzymes have both restriction and modification activities. Restriction depends upon the methylation status of the target DNA.
- Cleavage occurs approximately 1000 bp away from the recognition site.
- The recognition site is asymmetrical and is composed of two specific portions in which one portion contain 3–4 nucleotides while another portion contain 4–5 nucleotides and both the parts are separated by a non-specific spacer of about 6–8 nucleotides.
- They require S-adenosylmethionine (SAM), ATP, and magnesium ions (Mg2+) for activity.
- These enzymes are composed of mainly three subunits, a specificity subunit that determines the DNA recognition site, a restriction subunit, and a modification subunit.

TYPE II RESTRICTION ENZYMES:

- Restriction and modification are mediated by separate enzymes so it is possible to cleave DNA in the absence of modification. Although the two enzymes recognize the same target sequence, they can be purified separately from each other.
- Cleavage of nucleotide sequence occurs at the restriction site.
- These enzymes are used to recognize rotationally symmetrical sequence which is often

referred as palindromic sequence.

- These palindromic binding site may either be interrupted (e.g. BstEII recognizes the sequence 5´-GGTNACC-3´, where N can be any nucleotide) or continuous (e.g. KpnI recognizes the sequence 5´-GGTACC-3´).
- They require only Mg2+ as a cofactor and ATP is not needed for their activity.
- Type II endonucleases are widely used for mapping and reconstructing DNA in vitro because they recognize specific sites and cleave just at these sites.

Cleaving a single piece of DNA with multiple restriction enzymes creates a "DNA fingerprint."

The pattern of fragments can be compared to similar DNA from another source treated with the same enzymes, to determine if the two are identical or different.

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1-Biogas production in Indian scenario

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ABSTRACT

Cheap, clean, renewable, naturally occurring, and underutilized as an energy source is biogas. It ignites between 650°C and 750°C in temperature range and weights 20% less than air. It burns as a colorless, odorless gas with a blue glow. It typically burns with 60% efficiency in a regular biogas burner and has a caloric value of 20 MJ/m3. India's vast population means that it has a high energy requirement. Even though India produces less energy than is needed, up to now, forest resources have been used to meet this demand. Furthermore, this demand is increasing at a 4.6% annual rate due to the worldwide shortage of fossil fuel supplies. Biomass seems to be the most viable energy source, despite government exploration of energy production and sources, energy supply security, and carbon dioxide (CO_2) emission reduction. To begin with, biomass is a sustainable energy source. Secondly, using anaerobic digestion to convert biomass to bioenergy, such as biogas.

Keywords- Biogas, Methane, Anaerobic digestion, Hydrolysis

doi: https://zenodo.org/uploads/10736733

INTRODUCTION

The process of anaerobic digestion produces biogas. Reducing the quantity of waste products by turning biodegradable trash into usable fuel is crucial. Additionally, anaerobic digestion helps eliminate microorganisms that cause sickness. Microorganisms break down organic materials in anaerobic digestion when there is no oxygen present, the substance is sealed, and the temperature, pH, and moisture content are all controlled.

HISTORY OF BIOGAS IN INDIA

1859- First digestion plant was built at leper colony in Bombay, India
1897-Biogas used for lighting at Matunga leper asylum, Bombay.
1946-The first biogas plant designed IARI, Delhi.
1952-Development of the floating dome model, Grama Laxmi- III by Jashbai Patel.
1962-KVIC's entry into the field of biogas technology
1977-Development of Janata Model Biogas Plant
1981- Development of National Project on Biogas Development
2008- Incorporation of BDTC at IIT-Delhi
2009- Bio-CNG production/ utilization-Demonstration of integrated Technology Package on Biogas- Fertilization Plants (BGFP)
2013 - Bio-CNG production/ utilization forms part of 'Programme on Energy from Urban, Industrial and Agricultural Wastes/ Residues'
2013/2016- BIS Standard for Biogas Composition/further modification
2017 - Sustainable Alternative Towards Affordable Transportation (SATAT) launched for Bio-CNG/ CBG purchase and dispensation as auto fuel

The biological process that converts organic carbon to CO_2 and methane (CH_4) involves several steps: acidogenesis, acetogenesis, hydrolysis, and methanogenesis.

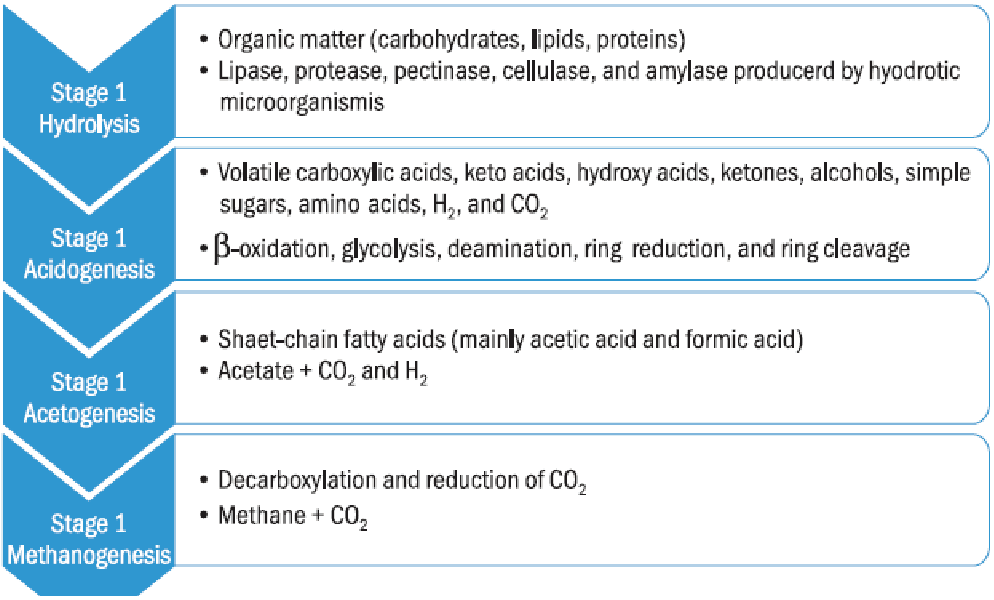
Steps involved in biogas production

HYDROLYSIS

The initial step of hydrolysis involves the breakdown of long chains of complex carbohydrates, proteins, and lipids into shorter forms such as sugars, amino acids, and fatty acids, respectively. This process is relatively slow and has the potential to constrain the overall rate of anaerobic digestion.

$C6H_{10}O_4+2H2O \rightarrow C_6H_{12}O_6+H_2$ [1]

Fig. 1. Scheme of anaerobic digestion



ACIDOGENESIS

In this step, the products of hydrolysis serve as substrates that are subsequently converted into higher organic acids such as propionic acid and butyric acid, which are further metabolized into acetic acid by acidogenic bacteria.

$\mathrm{C6H12O6} \longrightarrow \mathrm{2CH3CH2OH} + 2\mathrm{CO}_2$

$\mathrm{C6H12O}_6 + 2\mathrm{H}_2 \leftrightarrow \mathrm{2CH3CH2COOH} + \mathrm{2H2O}$ [2]

$\mathrm{C6H12O6} \longrightarrow \mathrm{3CH3COOH}$

ACETOGENESIS

The acetogenic bacteria then transform the higher organic acids into acetic acid and hydrogen gas as part of the process.

$\mathrm{CH}_3\mathrm{CH}_2\mathrm{COO}^- + 3\mathrm{H}_2\mathrm{O} \leftrightarrow \mathrm{CH}_3\mathrm{COO}^- + \mathrm{H}^+ + \mathrm{HCO3}^- + 3\mathrm{H}_2$

$\mathrm{C6H12O}_6 + \mathrm{2H2O} \leftrightarrow 2\mathrm{CH}_3\mathrm{COOH} + 2\mathrm{CO}_2 + 4\mathrm{H}_2$ [3]

$\mathrm{CH3CH2OH} + \mathrm{2H2O} \leftrightarrow \mathrm{CH}_3\mathrm{COO}^- + \mathrm{3H2} + \mathrm{H}^+$

METHANOGENESIS

In the final step, methanogenic bacteria metabolize acids, alcohols, carbon monoxide, carbon dioxide, and hydrogen to produce methane. These bacteria are highly sensitive to their environment, functioning exclusively under strict anaerobic conditions (Lettinga, van Nelsen, Hobma, et al. 1980).

$\mathrm{CH3COOH} \rightarrow \mathrm{CH}_4 + \mathrm{CO}_2$

$\mathrm{CO}_2 + 4\mathrm{H}_2 \longrightarrow \mathrm{CH4} + \mathrm{2H2O}$ [4]

$2\mathrm{CH}_3\mathrm{CH}_2\mathrm{OH} + \mathrm{CO}_2 \longrightarrow \mathrm{CH}_4 + \mathrm{2CH3COOH}$

BENEFITS OF BIOGAS

ENERGY PRODUCTION—POTENTIAL IN INDIA

In India, the usage of chemically manufactured fertilizers and fossil fuels is expected to be surpassed by biogas. For instance, 7.3 million tonnes of LPG and 22.7 billion m3 of natural gas (not including natural gas from liquefied petroleum gas, shrinkage, and LPG) were used in 2001–2002. In terms of heat energy, the annual amount is 1.08×10^{12} MJ, which is less than the 1.3×10^{12} MJ potential heat value that may be obtained from the biogas produced annually from animal excrement (Sevilla-Espinosa, Solorzano-Campo, and Bello-Mendoza 2010; Shastry, Nandy, Wate, et al. 2010).

The technology utilized in the production of biogas is more adaptable and valuable in an agro-ecosystem. The biogas can also be used as a fuel in place of firewood, agricultural waste, electricity, and other resources, depending on the kind of activity, availability, and other factors. It therefore supplies energy for lighting and cooking. Following anaerobic digestion, biogas facilities also produce leftover organic waste, which is more nutrient-dense than cattle excrement and typical organic fertilizers since it contains ammonia. Mix of installed electrical capacity in India

Types of biogas plants in India

The types of biogas plants commonly used in developing countries are as follows:

(i) Bag digester plant
(ii) Fixed dome digester plant
(iii) Floating drum digester plant
(iv) Vacvina biogas plant

(1) BAG DIGESTER PLANT

The bag digester plant, also known as a balloon plant, was first constructed in Taiwan in 1960. Typically, it consists of a plastic or rubber digester bag designed to be UV resistant, often made from materials such as neoprene, rubber, and RMP (red mud plastic). Organic waste, along with slurry, is introduced into the biodigester via inlet and outlet ducts for degradation. Biogas produced accumulates at the top of the bag, although in some instances, it may be collected in a separate bag. Residue is collected in the lower section. Functioning primarily as a plug flow reactor (PFR), the bag digester operates such that materials added daily theoretically move through the digester as a unit mass until the hydraulic retention time (HRT) is achieved. Subsequently, the digested mass exits the digester bag as a unit. A portion of the effluent is reintroduced into the inlet to serve as a seed for re-inoculating the bag digester (Kaparaju, Serranoa, and Angelidaki 2009).

The advantages of using the bag (balloon) digester are follows:

i. It is the most cost-effective option compared to other types of digesters.
ii. Installation and setup are straightforward and can be completed swiftly within hours.
iii. It features simple cleaning mechanisms, making maintenance hassle-free.

- The digester heats up along with its contents due to thin partitions in the reactor, utilizing sunlight or external heat source-The disadvantages of the bag (balloon) digester are as follows:
- Its lifespan is relatively short, approximately around 5 years.
- The digester is susceptible to damage and may pose challenges in restoration.
- Sludge removal and transportation to the field demand significant labor.
- It necessitates a consistent temperature.
- Insulating the digester is challenging.
- It relies on high-quality plastic, particularly PVC.

(2) FIXED DOME DIGESTER

This is a Chinese model biogas plant, first built in China around 1936. In this design, the digestion chamber and gas holder are integrated into a single unit. Examples of this design include Deenbandhu, Chinese fixed dome, CAMARTEC, as well as Janata and Janata II models.

Bacteria within the digester convert biomass into a liquid known as slurry (digested waste) and biogas. The biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), along with traces of other gases. Once collected in the dome-shaped gas holder, the slurry is transferred to the offset tank. The quantity of slurry produced is contingent upon factors such as the feed loading rate, its utilization, and gas generation. During gas production, the slurry is pressed backward and sideways, then directed to the offset tank. As gas is utilized, slurry is returned from the offset tank to the digester. These reciprocal movements facilitate the mixing of slurry phases, leading to altered phases through gradation mixing. Therefore, according to Stalin (2007), this model is regarded as a mixed digester reactor (CSTR, continuously stirred tank reactor).

The fixed dome digester is relatively inexpensive, making it economically viable with a lifespan of approximately up to 20 years. Because the majority of the structure remains below the earth's surface, it is safe and able to withstand cold temperatures. Additionally, the fluctuation in temperatures between day and night inside the biodigester is conducive to better biogas production by methanogens.

The advantages of the fixed dome digester are as follows:

4. Despite being low-cost, it offers significant advantages compared to other types.

5. It is reliable and has a lifespan of up to 20 years.
6. With its complete insulation and underground construction, it is considered the optimal digester type for biogas generation in colder climates, such as in countries like Bolivia.

The disadvantages of the fixed dome digester are as follows:

(i) Building it in bedrock areas poses significant challenges.

(ii) Technical skills are crucial for constructing the fixed dome and ensuring proper sealing to prevent gas seepage due to design flaws.

(iii) The lifespan of the fixed dome digester exceeds that of the Khadi and Village Industries Commission (KVIC) plant.

(3) FLOATING DRUM DIGESTER

This model is commonly referred to as the KVIC model, as it was endorsed and approved by KVIC (Jashu Bhai J. Patel developed the design of the floating drum biogas plant in 1962), and its utilization is widespread in India and around the globe.

The main or reactor tank is enclosed by a concrete wall and comprises two components: (i) an inlet for supplying slurry to the tank, and

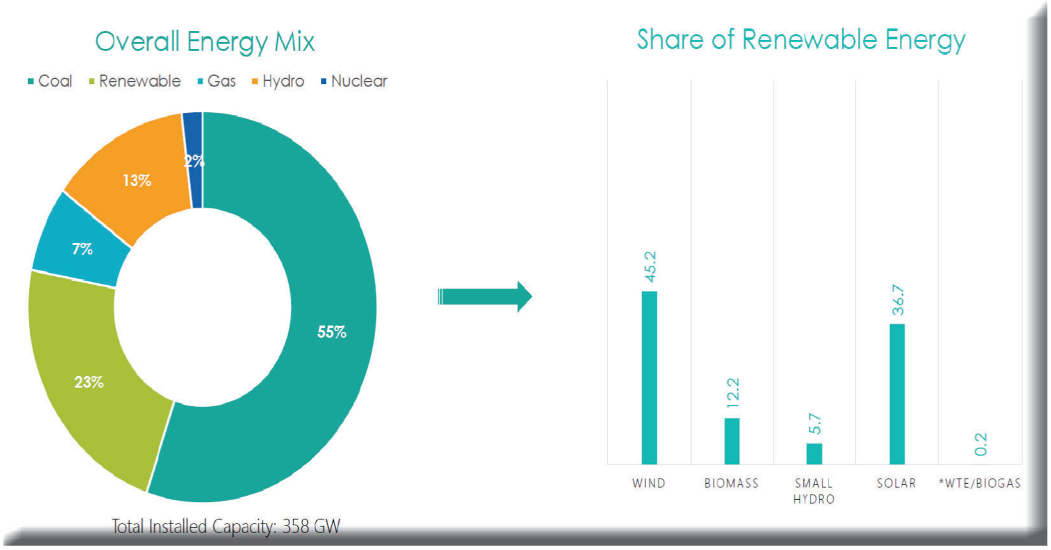
(ii) a stainless steel cylindrical dome positioned atop the slurry, housing an outlet pipe for collecting the gas produced. As the decomposed matter expands, the slurry overflows into the subsequent compartment, which can then be utilized as natural fertilizer.

The floating drum digester offers the advantage of maintaining constant gas pressure due to the weight of the drum.

However, its disadvantage lies in the use of stainless steel for the construction of the floating chamber, which is costly and requires ongoing maintenance and observation to prevent rusting.

(4) VACVINA BIOGAS PLANT

The VACVINA model represents an advancement from earlier biogas designs such as fixed dome and plastic container types. It features a



rectangular-shaped digester constructed with a volume capacity exceeding 5 m3, suitable for smaller animal farms.

Animal waste is supplied as feed from a trench located behind or below the animal shed. Biogas produced from the digester is collected and stored in two or three plastic bags, serving as fuel for the kitchen range. The advantages of the VACVINA model include:

I. Its simple design with minimal defects.
II. It is relatively inexpensive to maintain and can be constructed in limited space.
III. Suitable for colder climates due to the underground biogas digester and the external plastic gas reservoir.
IV. It has a higher probability of a longer lifespan.

Types of Biogas Reactors

According to Angelidaki and Sanders (2004) and Parawira, Murto, Zvauya, et al. (2004), achieving biodegradability of organic matter and surplus biogas generation in batch processes can be accomplished through the conventional anaerobic digestion method. This process proves effective due to the controlled and stable supply, as well as the steady state of the bioreactor, thereby maximizing production. The selection and classification of reactors are determined by the mixing of fluid (sludge

	Definition	**Installed Base**	**Future Potential**
SMALL BIOGAS PLANT	These consist of biogas plants of the size between 1 to 10 cubic meter capacities	A cumulative total of 4.8 million family type biogas plants have been set up in the country	Estimated potential of 12 million family plants
MEDIUM BIOGAS PLANT	Power generation capacity between 3 KW to 250 KW	There are about 300 small and medium biogas plants (5-25 KW)	Currently insignificant to be sized
LARGE BIOGAS PLANT	Equivalent power generation capacity above 250 KW	Few large scale installations, (50- 60 No.) most on demonstration basis:	The estimated potential from urban municipal wastes is projected at c. 5000 MW equivalent by 2023
INDUSTRIAL & MUNICIPAL WASTE BIOGAS PLANT	Plants based on feedstock derived from Industrial and Municipal waste	~ 40 power projects installed so far	The estimated potential of generation of power from industrial solid and liquid wastes is expected to increase to 2000 MW

and substrate) or particulate solid contents in the reactor, as reported by Stalin (2007). High-rate biofilms such as EGSB and UASB are employed for treating organic soluble matter, while slurry and solid wastes are treated in CSTRs (Kato, Field, and Lettinga 1997; Angelidaki, Ellegaard, Sorensen, et al. 2002).

I. CONTINUOUSLY STIRRED TANK REACTOR

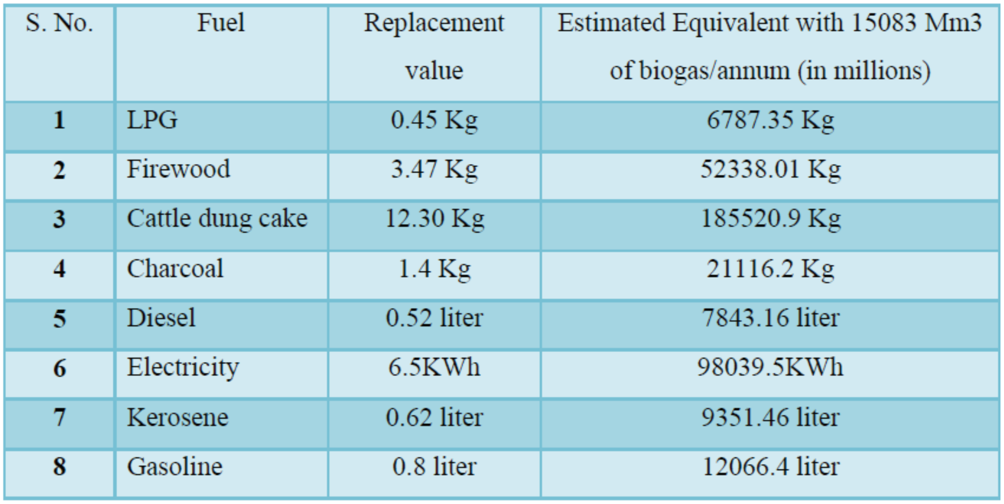
Demirel and Scherer (2008) documented the successful utilization of CSTR in the anaerobic digestion of energy crops and food remains. In the CSTR process, biomass is suspended in the main liquid and subsequently removed along with the effluent. By maintaining this process for 10–20 days, the hydraulic and sludge retention times become equivalent, thereby preventing the washout of slow-growing methanogens (Boe, 2006). Boe and Angelidaki (2009) observed that a single CSTR produces less CH4 compared to serial CSTRs when using the same industrial slurries or an equivalent volume of manure. Despite this, the CSTR process is practical, simple to operate, and offers numerous advantages (Kaparaju, Serranoa, and Angelidaki 2009).

II. UPFLOW ANAEROBIC SLUDGE BLANKET

The UASB (upflow anaerobic sludge blanket) reactor, developed in the 1970s by Lettinga, van Nelsen, Hobma, et al. (1980), is widely employed for biogas production through the treatment of various wastewater types (Shastry, Nandy, Wate, et al. 2010; Sevilla-Espinosa, Solorzano-Campo, and Bello-Mendoza 2010). In the UASB reactor, an immobilized cell is utilized, retaining biomass while substrate is pumped through, enabling a high organic loading rate. The success of the UASB concept hinges on the formation of a dense sludge bed at the reactor's bottom, where biological processes occur, facilitated by the accumulation of incoming suspended solids and bacterial growth (Seghezzo, Zeeman, and van Lier 1998). Natural turbulence in UASB systems is induced by influent flow, while biogas formation within the reactor enhances contact between wastewater and biomass.

Developed in the 1970s, the UASB reactor is extensively utilized for biogas production by treating various wastewater types. In the UASB reactor, wastewater is pumped through, leading to an increase in the loading rate and retention of biomass through immobilized cells. (Kaparaju, Serranoa, and Angelidaki 2009).

The success of the UASB application relies on the formation of a sludge layer created by suspended solids in wastewater, as it



S. No.	Fuel	Replacement value	Estimated Equivalent with 15083 Mm3 of biogas/annum (in millions)
1	LPG	0.45 Kg	6787.35 Kg
2	Firewood	3.47 Kg	52338.01 Kg
3	Cattle dung cake	12.30 Kg	185520.9 Kg
4	Charcoal	1.4 Kg	21116.2 Kg
5	Diesel	0.52 liter	7843.16 liter
6	Electricity	6.5KWh	98039.5KWh
7	Kerosene	0.62 liter	9351.46 liter
8	Gasoline	0.8 liter	12066.4 liter

is where microbial degradation and digestion of organic matter occur (Seghezzo, Zeeman, van Lier, et al. 1998). The resulting biogas facilitates significant interaction between wastewater and biomass, while influent flow induces natural turbulence in the UASB systems.

III. EXPANDED GRANULAR SLUDGE BED

De Man, Vander Last, and Lettinga (1988) introduced the concept of the expanded granular sludge bed (EGSB) as a modification to the traditional UASB reactor. Both EGSB and UASB utilize granular sludge inoculation; however, adjustments in hydrodynamic settings such as superficial velocity and Ks enhance mixing and contact between sludge and wastewater specifically in the EGSB.

PROBLEMS AND ISSUES ENCOUNTERED

TECHNICAL

The failure of numerous biogas facilities is often linked to technical operational issues, which can manifest in various forms, including inadequate maintenance, negligence, or equipment deterioration such as rusting over time. A 1995 study analyzing a sample of 24,501 biogas plants across 432 villages in India found that only about 53% of these plants were active. Given the prevalence of technical challenges, the subsequent discussion on planning and policies should be taken into consideration.

INPUT PROBLEMS

In India, cattle excreta is commonly collected and utilized as the primary feedstock for biogas digesters, while pig and human excreta are deemed unacceptable (UNAPCAEM 2007). Despite approximately 20% of rural households owning four or five cattle, a biogas plant exclusively relying on cow dung requires a similar number of calves per household for optimal operation. Villagers' reluctance to utilize waste materials other than cattle excrement results in underfed biogas plants, exacerbating the scarcity issue and complicating solutions.

HUMAN RESOURCES

- For the success and sustainability of NBMMP, it is crucial to have well-trained laborers constructing the biogas plants. However, biogas dissemination programs in India often face challenges due to the lack of qualified staff to provide training, supervision, reporting, and program leadership.
- Shortage of staff for training and developing local capacity.

REPORTING

- Inaccurate reporting of achievements:
- Discrepancies were noted in the reporting of data and achievement of goals at the block, district, and state levels by PEO. The PEO highlighted that record-keeping at higher levels lacks authenticity.
- Improper maintenance of reports.

TRAINING/MONITORING

- To ensure that troops participating in NBMMP are well-informed and satisfied with their duties, training plans are essential.
- Moreover, systematic monitoring is lacking. Each RBDTC is required to conduct random case verifications of 500 biogas plants established in a specified region

at predetermined times. However, due to the shortage of administrative manpower, this goal is rarely achieved. The effectiveness of the reporting mechanism is compromised, and progress reports for these biogas plants are often submitted without proper oversight and authorization.

POLITICAL/BUREAUCRATIC:

- In India, the FTBP is a government-funded program that involves multiple states, district bureaus, funding institutions, training centers, and NGOs.
- Agency multiplicity and procedural delays- Additionally, because the clearance procedure is so drawn out and bureaucratic, firms encounter delays in receiving technical approval for raw materials like steel and cement. The government controls the transportation of steel and cement, which are in short supply in India, and sets the pricing for transportation based on quotas.

Biogas Programme

(PHASE-I) FOR FY 2021-22 TO 2025-26

A government of India initiative through Ministry of New and Renewable Energy.

- There is significant potential for setting up biogas plants in India, given the large livestock population of 535.78 million, which includes approximately 302 million bovines (comprising cattle, buffalo, mithun, and yak). The livestock sector makes a substantial contribution to India's GDP and is expected to grow further. The dissemination of biogas technology represents a boon for Indian farmers, offering both direct and collateral benefits (Fu, Achu, Kreuger, et al. 2010).
- Biogas typically comprises about 55-65% methane, 35-44% carbon dioxide, and traces of other gases like hydrogen sulphide, nitrogen, and ammonia. In its raw form, without any purification, biogas can serve as a clean cooking fuel similar to LPG, for lighting, motive power, and electricity generation. It can also substitute diesel in diesel engines, with replacements of up to 80% achievable, and in 100% biogas engines. Moreover, biogas can be purified and upgraded to attain up to 98% methane content purity, transforming it into Compressed Bio-Gas (CBG), suitable for transportation or filling cylinders at high pressures of around 250 bar.
- Initially, biogas plants were designed for digesting cattle dung. However, technological advancements over time have enabled the bio-methanation of various types of biomass materials and organic wastes. Biogas plant designs are now available in sizes ranging from 1 m3 to over 1000 m^3, with multiples of that size possible to achieve larger plant sizes. These plants can be installed for various purposes, including family/household use, small farmers, dairy farmers, and for community, institutional, and industrial/commercial applications, depending on the availability of raw materials.

About the Biogas programme

The Ministry of New and Renewable Energy (MNRE), Government of India, introduced the National Bioenergy Programme on November 2nd, 2022. MNRE has extended the National Bioenergy Programme for the period from FY 2021-22 to 2025-26, with implementation planned in two phases. Phase-I of the Programme has been approved with a budget outlay of Rs. 858 crore, including Rs. 100 Crore allocated for the Biogas Programme. This funding aims to support the establishment of small (1 m3 to 25 m3 biogas per day) and medium-sized biogas plants, ranging from above 25 m3 to 2500 m3 biogas generation per day. These plants are expected to have corresponding power generation capacities ranging from 3 kW to 250 kW from biogas or raw biogas for thermal energy/cooling applications. (Puyol, Mohedano, Sanz, et al. 2009; Kalogo and Verstraete 1999).

The Ministry of New and Renewable Energy, Government of India, launched the Biogas programme with the following objectives:

- Setting up of biogas plants for clean cooking fuel, lighting, meeting thermal and small power needs of users which results in GHG reduction, improved sanitation, women empowerment and creation of rural employment.
- **ORGANIC ENRICHED BIO-MANURE:** The digested slurry from biogas plants, a rich source of manure, shall benefit farmers in supplementing / reducing of use of chemical fertilizers.

Conclusion

For several decades, biogas has proven to be the most suitable machinery for utilizing available resources efficiently. It is recognized as a clean, hygienic, and cost-effective fuel that is environmentally friendly. With biogas, women in villages no longer need to spend hours gathering firewood for cooking and burning, freeing up time for other activities. Additionally, a smokeless and soot-free kitchen reduces the risk of lung and throat infections for women, enabling them to live longer, healthier lives. Furthermore, biogas has the capacity to fulfill the fuel demands of households, agricultural lands, and industries comprehensively.

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