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Integration of Artificial Intelligence in Plant Breeding

*Pallavi Puhan¹, Prithviraj K², Satyam Kumar Mehta³ and
Jakkuva Laharika Surya Sai⁴

¹Ph.D. Scholar, Department of Seed Science and Technology, College of Agriculture,
OUAT, Siripur, Suryanagar, Bhubaneswar, Odisha, India

²M.Sc. Research Scholar, Department of Genetics and Plant Breeding, Annamalai
University, Annamalai Nagar, Chidambaram Tamil Nadu, India

³Research Scholar, High Altitude Plant Physiology Research Centre, Hemvati Nandan
Bahuguna Garhwal University, Srinagar, Pauri Garhwal, Uttarakhand, India

⁴Research scholar, Agricultural engineering, Aditya University, Aditya Nagar, ADB
Road, Surampalem, East Godavari, Andhra Pradesh, India

*Corresponding Author's email: pllvpuhan@gmail.com

The integration of Artificial Intelligence (AI) in plant breeding is revolutionizing modern agricultural research and crop improvement. Traditional plant breeding methods often require many years of experimentation, field trials, and extensive data analysis to develop improved crop varieties. AI technologies such as machine learning, data analytics, and predictive modeling enable researchers to process large genomic, phenotypic, and environmental datasets with greater efficiency and accuracy. These technologies help identify important traits such as high yield potential, disease resistance, and tolerance to environmental stresses. AI also supports advanced techniques such as genomic selection, high-throughput phenotyping, and automated disease detection using image recognition and sensor-based monitoring systems. By analyzing complex biological patterns, AI models can predict plant performance and guide breeders in selecting superior genotypes early in the breeding process. This significantly reduces the time, cost, and uncertainty associated with traditional breeding approaches. Furthermore, AI contributes to the development of climate-resilient crop varieties capable of adapting to changing environmental conditions. Overall, the integration of AI in plant breeding enhances breeding efficiency, accelerates crop improvement programs, and plays a vital role in ensuring sustainable agriculture and global food security.

Introduction

The integration of Artificial Intelligence (AI) in plant breeding is transforming the way scientists develop improved crop varieties. Traditional plant breeding methods often require many years of field trials, large datasets, and careful observation to identify desirable traits such as higher yield, disease resistance, and climate tolerance. AI technologies, including machine learning, data analytics, and predictive modeling, help researchers analyze complex biological data more efficiently and accurately. By processing large volumes of genomic, phenotypic, and environmental data, AI can identify patterns and relationships that may not be easily detected through conventional methods. This enables plant breeders to make faster and more precise decisions in selecting superior plant traits. Additionally, AI supports high-throughput phenotyping, automated image analysis, and prediction of breeding outcomes, which significantly reduces time and cost. As global food demand continues to increase and climate change threatens crop productivity, integrating AI into plant breeding offers a promising approach to accelerate crop improvement and ensure sustainable agricultural development.

Role of Artificial Intelligence in Plant Breeding

Artificial Intelligence (AI) is transforming plant breeding by improving the speed and accuracy of crop improvement programs. AI techniques such as machine learning and data analytics help researchers analyze large datasets from genomics, phenotyping, and environmental studies. This enables breeders to identify desirable traits like higher yield, disease resistance, and climate tolerance more efficiently. AI models can also predict plant performance under different environmental conditions, reducing the time required for field trials. By supporting precise decision-making and accelerating the selection process, the integration of AI in plant breeding helps develop improved crop varieties that can meet the growing global demand for food.

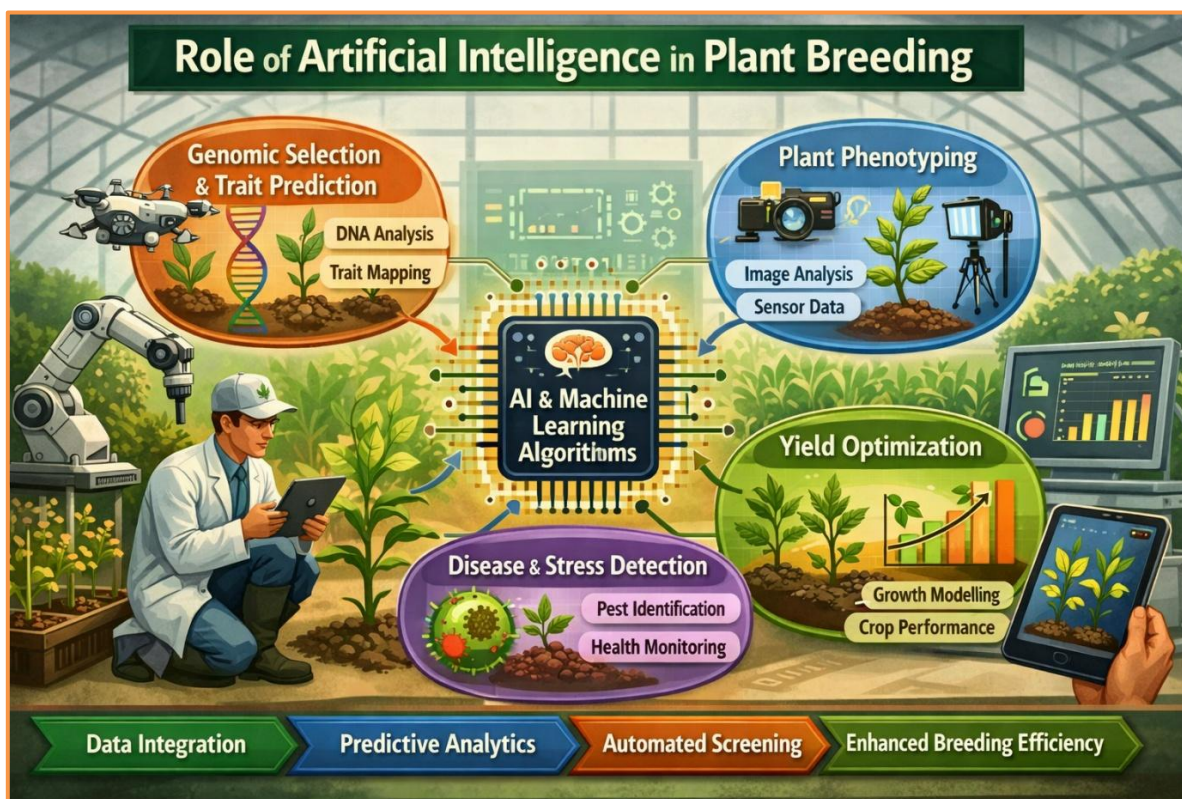


Figure 1 Role of artificial intelligence in plant breeding

Key Applications of AI in Plant Breeding

Artificial Intelligence improves plant breeding by analyzing large genomic and phenotypic datasets to identify desirable traits quickly. It supports predictive modeling for yield, disease resistance, and climate adaptability. AI also accelerates marker-assisted selection, optimizes breeding strategies, and enhances precision phenotyping, helping breeders develop improved crop varieties more efficiently.

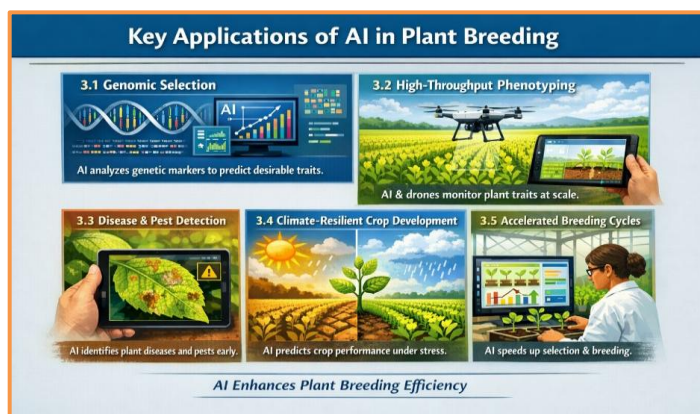


Figure 2. Key Applications of AI in Plant Breeding

Genomic Selection

Genomic selection combined with artificial intelligence is transforming modern plant breeding. Large genomic datasets contain complex patterns that are difficult to interpret using traditional statistical methods. AI techniques, such as machine learning and deep learning, can analyze these patterns to predict the genetic potential of plants with higher accuracy. By integrating genomic data with environmental and phenotypic information, AI models help

breeders identify superior genotypes early in the breeding cycle. This reduces the time and cost required to develop improved crop varieties. As a result, the integration of AI with genomic selection supports faster development of high-yielding, resilient, and climate-adapted crops.

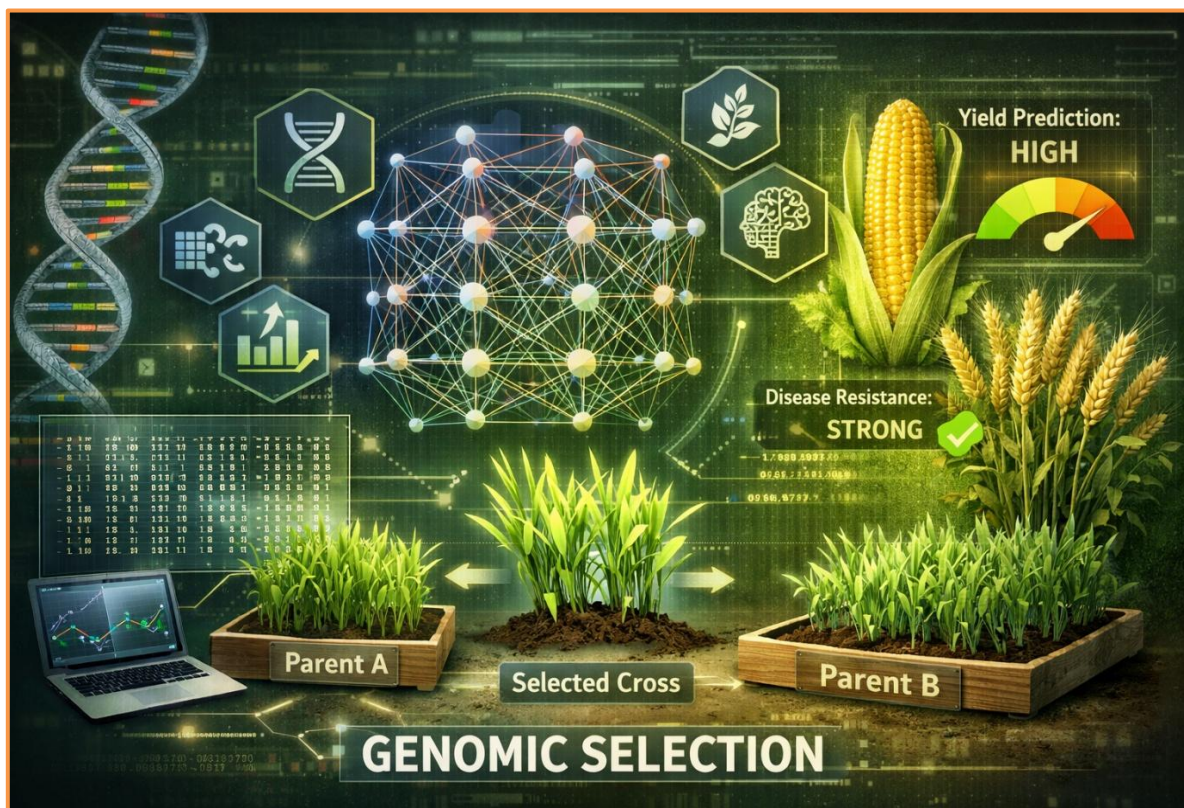


Figure 3 Process of Genome selection using AI

High-Throughput Phenotyping

High-throughput phenotyping combined with artificial intelligence is transforming modern plant breeding. Advanced sensors, imaging systems, and drones collect large amounts of data on plant traits such as growth, stress response, and yield potential. Artificial intelligence algorithms analyze this complex data quickly and accurately, identifying patterns that may not be visible through traditional methods. By

integrating AI with phenotyping platforms, breeders can evaluate thousands of plant samples in a short time. This improves the selection of superior genotypes and accelerates breeding cycles. As a result, crop development becomes faster, more precise, and better suited to address global challenges such as climate change, food security, and sustainable agriculture.

Disease and Pest Detection

The integration of Artificial Intelligence (AI) in plant breeding has greatly improved the detection of plant diseases and pests. AI-powered image recognition and machine learning algorithms analyze leaf patterns, color changes, and other symptoms to identify infections at an early stage. These systems can process large volumes of field data quickly, enabling breeders to monitor crop health with greater accuracy. Early detection helps in selecting



Figure 4. Integrating AI with phenotyping platforms

resistant plant varieties and reduces crop losses. Additionally, AI tools support real-time monitoring through drones and smart sensors. By improving the speed and precision of disease and pest identification, AI contributes to the development of healthier and more resilient crop varieties.



Figure 5 Process of AI-powered image recognition and machine learning to determine early detection of crop disease

Climate-Resilient Crop Development

Climate-resilient crop development is becoming increasingly important as agriculture faces rising temperatures, irregular rainfall, and more frequent extreme weather events. The integration of Artificial Intelligence (AI) in plant breeding offers powerful tools to address these challenges. AI can analyze large genomic, environmental, and phenotypic datasets to identify traits linked to drought tolerance, heat resistance, and improved yield stability. Machine learning models help breeders predict the performance of new crop varieties faster and more accurately. This accelerates the development of resilient cultivars suited to changing climates. By improving decision-making and reducing breeding time, AI supports sustainable agriculture and enhances global food security.



Figure 6 AI driven Climate Resilient crop development

Accelerated Breeding Cycles

The integration of Artificial Intelligence (AI) in plant breeding is transforming the speed at which improved crop varieties can be developed. Traditionally, plant breeding requires multiple generations of selection and testing, often taking many years to produce a new variety. AI helps accelerate breeding cycles by analyzing large datasets and predicting desirable genetic traits more efficiently than conventional methods. Machine learning algorithms can process information from genomic data, environmental conditions, and plant phenotypes to identify promising parent combinations and predict breeding outcomes. This reduces the need for lengthy trial-and-error experiments. AI tools can also assist breeders in

selecting plants with optimal traits such as higher yield, drought tolerance, and disease resistance at earlier growth stages.

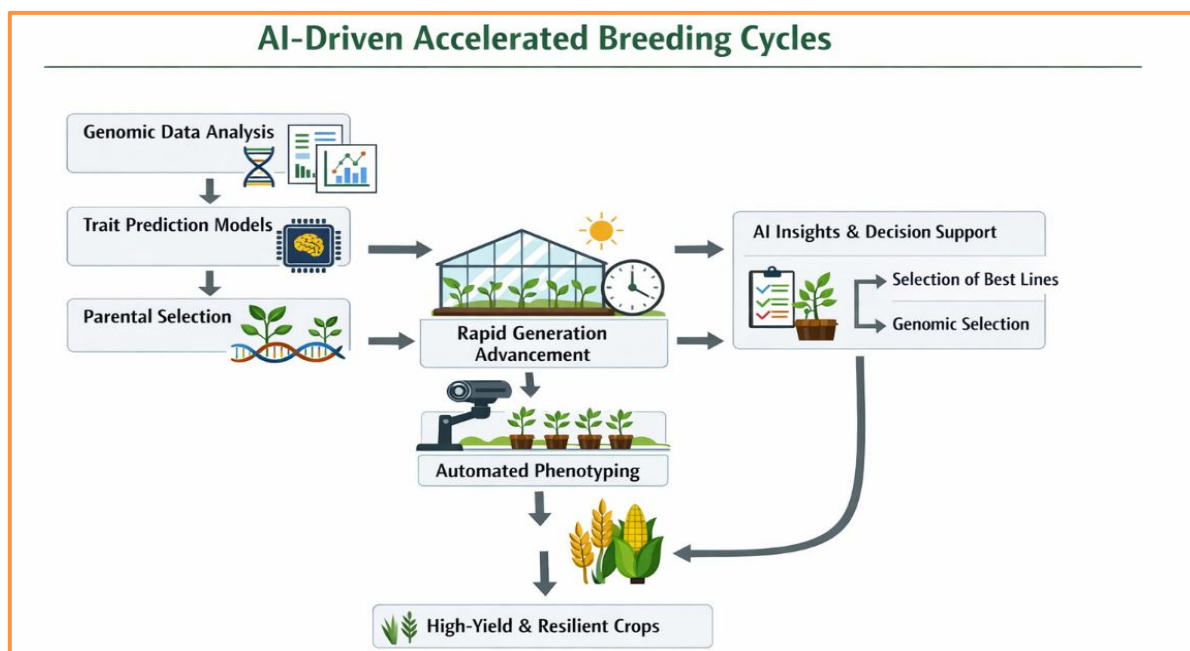


Figure 7. AI driven breeding cycle flowchart depicting combination of predictive models with controlled growth environments

Another key advantage of AI is its ability to support technologies like genomic selection and speed breeding. By combining predictive models with controlled growth environments, breeders can shorten generation time and rapidly evaluate multiple breeding lines. AI-driven image analysis and sensor data also allow continuous monitoring of plant growth and health, enabling faster and more accurate selection decisions.

Table 1 Combining predictive models with controlled growth environments

Component	Description	Role of Artificial Intelligence	Impact on Breeding Cycle
Genomic Data Analysis	Analysis of DNA markers and genomic sequences of breeding lines.	AI and machine learning models process large genomic datasets to identify gene–trait associations.	Enables rapid identification of desirable genetic traits.
Parental Selection	Selection of parent plants for hybridization based on desirable characteristics.	Predictive algorithms evaluate potential parent combinations using historical and genomic data.	Improves accuracy and reduces time required for parent selection.
Phenotypic Evaluation	Measurement of observable plant traits such as height, yield, and disease resistance.	AI-based image recognition and sensor technologies automatically analyze plant phenotypes.	Allows faster and more precise trait assessment.
Genomic Selection	Prediction of breeding values using genome-wide markers.	Machine learning models estimate the genetic potential of plants early in development.	Reduces the number of breeding generations needed.
Speed Breeding Integration	Controlled environment techniques to accelerate plant growth and reproduction.	AI optimizes environmental conditions and predicts optimal growth parameters.	Shortens generation time and accelerates breeding cycles.
Decision Support Systems	Tools that assist breeders in planning crosses and selecting lines.	AI-driven decision support systems integrate multiple datasets for informed breeding decisions.	Enhances efficiency and reduces experimental uncertainty.
Overall Outcome	Development of improved crop varieties.	AI integrates genomic, phenotypic, and environmental data for precise predictions.	Leads to faster development of high-yielding and climate-resilient crops.

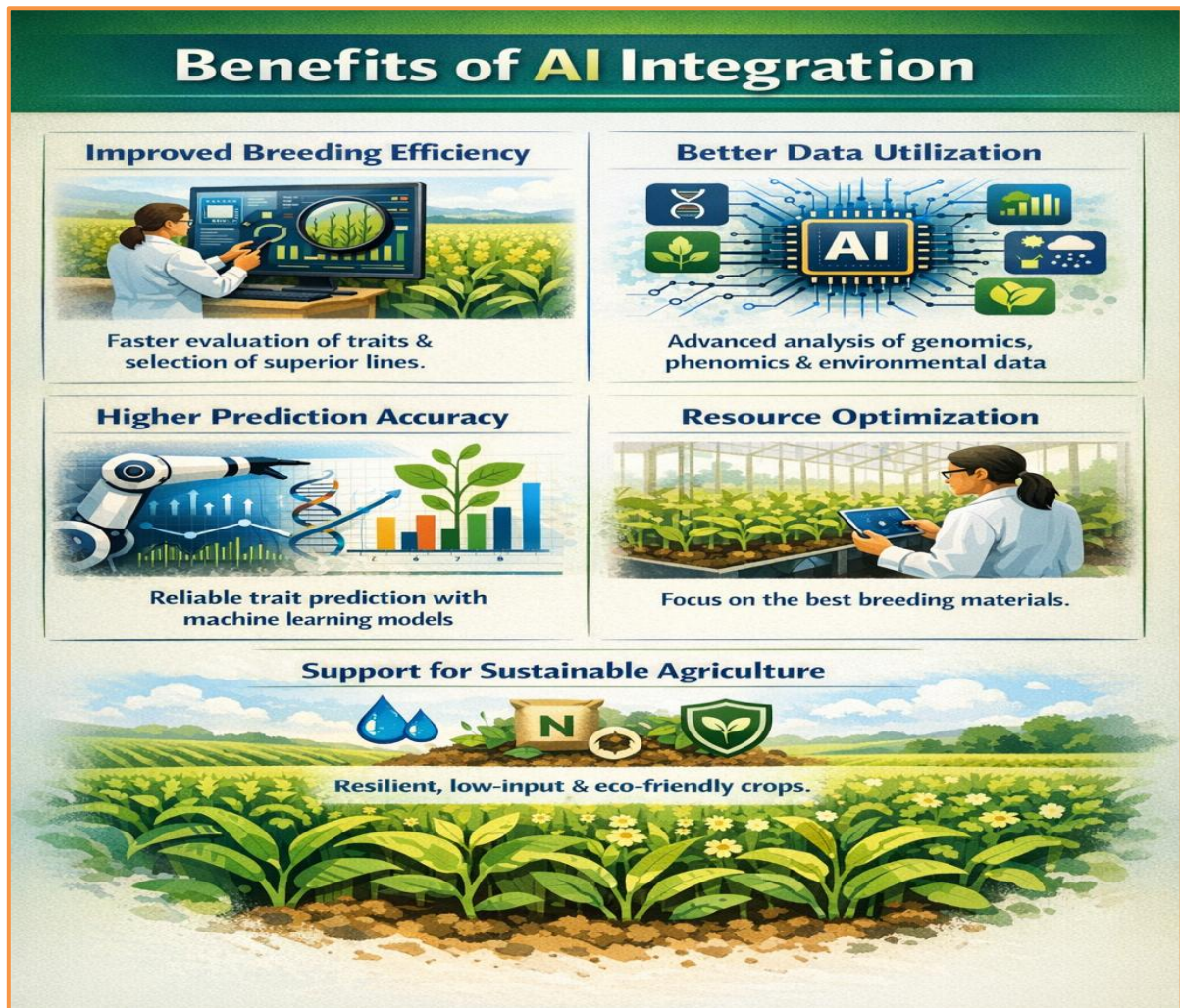


Figure 8. Benefits of AI Integration



Figure 9. The challenges that hinder the full adoption of AI in plant breeding

Table 2. Future Prospects of Artificial intelligence in plant breeding

Future Aspect	Description	Expected Impact on Plant Breeding
AI-Driven Genomic Selection	Advanced machine learning models will analyze genomic data to predict plant performance and desirable traits before field testing.	Accelerates breeding cycles and increases the probability of selecting superior genotypes.
High-Throughput Phenotyping	AI combined with drones, sensors, and imaging systems will automatically measure plant traits such as growth rate, canopy structure, and stress symptoms.	Enables rapid and precise collection of phenotypic data for large breeding populations.
Climate-Resilient Crop Development	AI models will simulate crop responses under various climatic conditions, helping breeders identify genotypes suited for drought, heat, or salinity.	Supports development of varieties adapted to climate change and environmental variability.
Integration of Multi-Omics Data	AI will integrate genomics, transcriptomics, proteomics, and metabolomics datasets to understand complex trait interactions.	Improves the identification of genes controlling yield, quality, and stress tolerance.
Automated Breeding Decision Systems	Intelligent decision-support platforms will recommend crossing strategies, parent selection, and breeding pipeline optimization.	Reduces human bias and increases efficiency in breeding program management.
Precision Gene Editing Support	AI algorithms will assist in identifying target genes and predicting outcomes of technologies such as CRISPR-based genome editing.	Enables more accurate

Conclusion

The integration of Artificial Intelligence in plant breeding represents a major advancement in modern agricultural science. AI technologies such as machine learning, predictive analytics, and automated data processing enable plant breeders to analyze complex genomic, phenotypic, and environmental datasets with greater precision and speed. These tools support important breeding activities including genomic selection, high-throughput phenotyping, disease detection, and the development of climate-resilient crops. As a result, breeders can identify desirable plant traits more efficiently and shorten the time required to develop improved crop varieties. AI-driven breeding approaches also improve decision-making by predicting plant performance under different environmental conditions. This capability helps researchers select superior genotypes at earlier stages, reducing the need for long and expensive field trials. In addition, AI facilitates the efficient use of resources and strengthens the accuracy of breeding programs. However, the successful adoption of AI in plant breeding requires high-quality datasets, advanced computational infrastructure, and skilled professionals who can integrate biological knowledge with data science. Addressing these challenges will be essential for maximizing the potential of AI technologies. Overall, AI has the potential to transform plant breeding by accelerating crop improvement, supporting sustainable agriculture, and helping meet the increasing global demand for food in the face of climate change and limited natural resources.

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