BRIDGING FIELD INNOVATION ADVANCES:

"HOW ARTIFICIAL INTELLIGENCE IS REVOLUTIONIZING CLIMATE SMART CROP BREEDING"

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INTRODUCTION:

Artificial intelligence (AI) often known as machine intelligence refers to the development of computer systems that are capable performing activities that typically require human intelligence. The existing condition, Artificial intelligence (AI) has emerged as a revolutionary field that is widely employed indoors for plant science and offers a significant potential to shape modern crop breeding. The various "omics" techniques viz., phenomics and enviromics are render ways it possible to expound the intricate biological systems that drive crop functions in response to environmental factors. Notably, Plant breeders have precise tools to assess the crucial agronomic characters for larger-sized germplasm at shorter time intervals during the early growth stages by owing these "omics" approaches. Therefore, emphasizing to link the genotype to phenotype is hampered by the hurdle challenge and disrupt the optimal application of high-throughput field phenotyping, genomics, and enviromics. At current trending, omics technology with plant breeding is a rapid emerging discipline in order to improve crop yield.

As the population is drastically increasing, climate changes, arable lands etc., based on these have more demand to increase the crop yield through high throughput techniques with high accuracy. Therefore, prior to work, the field of artificial intelligence came into existence recently emerging technology to possess the ultimate potential to assist in climate smart crop breeding. Under an array of climatic and environmental changes, Climate-resilient crops are able to sustain or improve crop yields and quality and it will also allow crops to address the interlinked challenges of food security and climate change.

IMPLICATIONS OF AI TECHNOLOGY IN CROP IMPROVEMENT

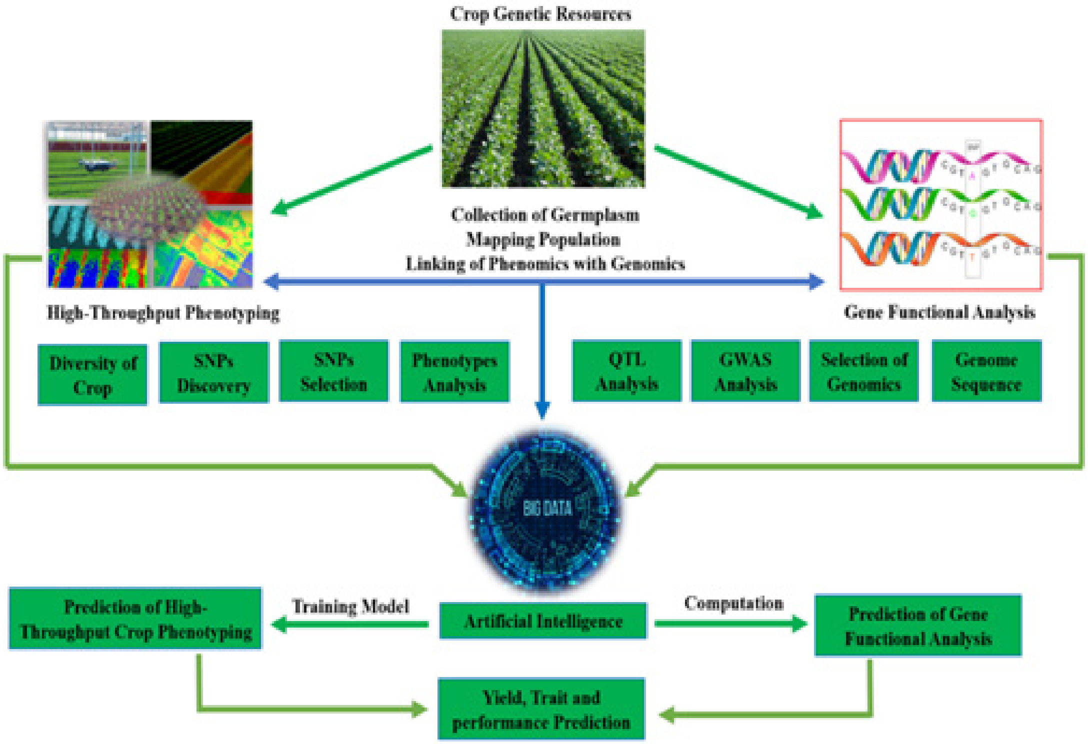
Nowadays, the software used in AI are complementary metal-oxide-semiconductor (CMOS) hardware to compute the activities used in agriculture. Some machine-learning algorithms include deep neural network (DNN), artificial neural network (ANN), random forest (RF), and support vector machine (SVM). Advanced hi-tech equipment such as the internet of things (IoT). Machine learning (ML) is a branch of AI in which computers uses substantial training datasets to find associations. Big data can be defined as the collection of meteorological or Earth System-related measurements, along with high spatial and temporal resolution Earth System model (ESM) outputs for analysis. The unique use of computer graphics processing units (GPUs), with GPU speed improving at a quicker rate than ordinary central processing units, contributes to the improved computing capabilities through application of ML methods. This is a novel use of computer memory to bring computations much closer to the location of data storage and more efficient. The foremost advantage of using AI in breeding is that it ensures ongoing farm monitoring, which enhances the breeder's work. On the contrary, breeders may be able to allocate more time to higher-value jobs by spending less time in their buildings as a result of farm automation and data generalization. AI significantly reduces the time required for data identification and processing. Breeders and technical advisors become more self-assured and responsive, enabling them to take measures when required. AI techniques such as high-throughput genomics and phenomics to improved breeding, have streamlined the process of developing new plant varieties. Therefore, the applications of machine learning techniques in marker-assisted selection, genomic selection and genomic prediction have increased and its ability to revolutionize agriculture and ensure global food security in future.

UNLEASHING THE POWER OF AI: TRANSFORMING GENE FUNCTION ANALYSIS

In recent decades, tremendous amount of data has been generated in the biological sciences due to the rapid development of high-throughput technologies. "AI has more potential uses in in-depth genome investigation in future and is currently being employed extensively in plant genomics. A wide range of ML tools and algorithms are available for various bioinformatics analysis, includes protein-coding gene identification, cis-regulatory element identification, gene expression, subcellular location, protein-protein interaction, gene ontology, metabolic pathways, phenotypes, and genomic prediction. Information transfer from a model plant to a crop of interest to address the comparative genomic studies through AI algorithms. In order to anticipate gene functions or gene expressions on a character can be achieved by numerous sorts of expressions or sequencing data approaches. The bioinformatics AI technology enables it feasible to measure the simultaneous expressions of many genes, or even all genes present in the genome under a wide assortment of scenarios.

BRIDGING GENOTYPE TO PHENOTYPE VIA AI

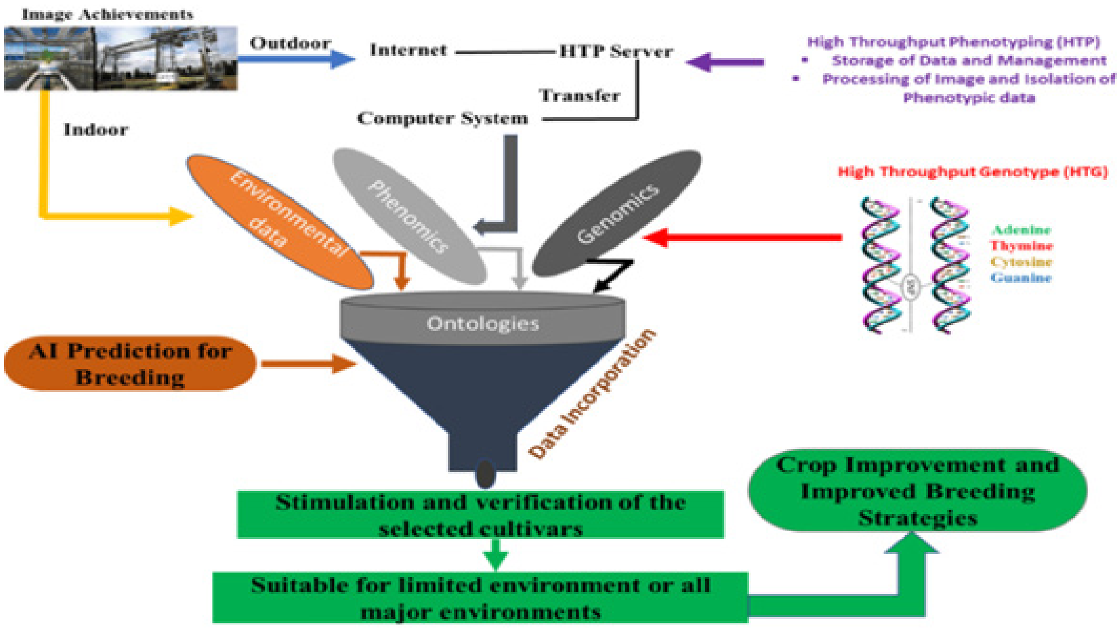
The main approach of breeding techniques is focused on linking the genotype with the crop phenotype in accurate and precise manner. In advanced breeding, linking the whole of the genome information to high-throughput phenotypes remains a massive challenge, and is impeding the optimal application of field phenotyping and omics. AI is capable of efficiently differentiating phenomics and genomics data through germplasm collection and mapping populations. Many significant amounts of data are generated by factors like crop diversity,



single nucleotide polymorphisms (SNPs) detection and selection, quantitative trait loci (QTL) analysis, genome-wide association study (GWAS) analysis, and genomic selection and sequences; AI can assess and connect the phenomics and genomics data to enhances the breeding strategies. High-throughput crop phenotyping and gene functional analysis can be predicted by AI coupled with a computation and training model. It also forecast crop characteristics and yield performance. Consequently, the integration of AI with phenomics and genomics tools can allow for rapid gene identification associated with the crop phenotypes that ultimately speed up crop improvement programs. In order to connect high-throughput genomics and phenomics and perhaps produce improved breeding techniques, we summarize how to apply AI technology is represented in below figure.

Researchers have utilized artificial intelligence (AI) and its models to adjust the flow of information from generic DNA to genetic-based phenotypes in order to look into potential variants in natural populations. AI aids breeders in investigating genetic loci, enabling high-throughput crop phenotyping and gene functional analysis. It triggers genome algorithms and collects high-throughput data from large crop germplasm and breeding populations. The comprehensive database can integrate AI technology for crop phenotypic diversity, SNPs polymorphisms, QTL analysis, GWAS analysis, genomics selection, and genome sequence. AI can predict crop phenotype to develop novel breeding strategies, and facilitate agricultural output. It can be combined with bioinformatics and genome sequencing analysis to interpret molecular repertories such as transcription factor binding sites, long non-coding RNAs (lncRNAs), microRNA (miRNAs), epistatic modifications, coding genes, targeted polyadenylation sites, as well as cis-regulatory elements (CREs).

A significant amount of heterogeneous-related phenotypic and genotypic data has been inserted into several agricultural, offering breeders insight into potential resources to untangle novel trait-identified candidate genes. AI offers a new benchmark for analysing large datasets of phenotypic and genotypic data in crop databases which provides insights into novel trait-identified candidate genes and identifying previously unknown genes for crop improvements. AI is increasingly crucial in analysing genomic and phenomics data to enhance agricultural climate resilience. NGS-based genotyping improves gene-mapping resolution and GWAS analysis, making envirotyping data accessible in crop breeding. AI is revolutionizing crop breeding by making envirotyping data accessible, addressing climate change's significant impact on the environment and crop production. Envirotyping is a third technology that helps decode environmental influences on crop breeding. It includes genotype-by-environment interaction (GEI), environmental signals, responsive genes,



biotic and abiotic stresses and integrative phenotyping. Climate-smart crops and soils are adapted for effective breeding programs, using genomic technologies and high-throughput phenotyping to guide and notify the breeding methods for climate-smart breeding.

Breeders can use genetic and phenotypic data to adjust crops to their environment. This can be done through advanced selection or genome editing techniques. Genomic and phenomics data will need to be integrated into comprehensive clade-specific databases and platforms, as well as accessible tools that breeders may utilize to inform the selection of climate-adapted characteristics, to effectively translate research into the field. From below figure, the proposed breeding scheme integrates genotypic, phenotypic, and envirotypic information, collecting phenotypic data from indoor and outdoor environments by high-throughput robotic systems and the phenotypic information from various environments will transfer to a high-throughput phenotyping (HTP) server via Internet. The multiple datasets will take the genotypic, phenotypic, and envirotypic information together, and the G × E interaction (GEI) will quantify by multiple environments. AI technology, specifically machine learning and deep learning, is used for cultivar selection in specific environments.

TOWARDS OPPORTUNITIES FOR AI BREEDING IN FUTURE

In recent years, there has been notable increase in growth of importance in AI which has sparked technology about its potential usage worldwide in all fields. Modern Plant breeding is required to capitalise on the digital revolution. Researchers and breeders must evaluate computer-generated suggestions against farmer's demands to be successful in their future efforts. Furthermore, AI will focus on developing novel, human-centered techniques and evaluating how robotics might be applied to range of global industries and businesses. Additionally, AI will change how businesses grow and compete globally by bringing new manufacturing companies that will increase profitability. The global agricultural breeding sector will benefit from the development of various AI systems since they assume the availability of symbolic structures, such as reasoning ability and knowledge existence. AI algorithms may be applied to comparative genomics studies or information transfer from a model plant to a crop of interest. AI applications will become more broadly available as farmers and breeders will be able to send the data into cloud-based AI applications via portable devices, drones, and agriculture equipment platforms. While accurate, the phenomics and genomics data acquired through ML and DL are insufficient to fully rely on technology to expedite the still difficult, expensive and time-consuming process of breeding. Epigenomics, transcriptomics, proteomics, metabolomics, and phenomics analysis in genomes still provide minimal information. AI will efficiently revolutionize the "omics" approaches and breeding management by developing numerous genotypes and phenotypes, screening them using model-based envirotyping, and advancing segregating material through speed-breeding management or fast-generation advancement.