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Artificial Intelligence: Transforming Plant Breeding for Sustainability in Agriculture

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ABSTRACT:

Artificial Intelligence (AI) is playing a crucial role in transforming many industries, including agriculture. AI uses the provided database, learning from experiences, solving problems, and making decisions. Machine Learning (ML) develops algorithms for performing functions based on the provided database. The article discusses how AI can be used in plant breeding to enhance crop production with increased precision and efficiency, integrating multiple breeding techniques such as marker-assisted selection and genome editing. AI can be extensively used to improve and multiply desired breeds to meet the demand of the growing population without compromising the quality of the crop, ultimately leading to global food security and sustainability in agriculture.

Keywords: Artificial Intelligence, Breeding, Crop Improvement, Sustainability in Agriculture and Genomic Selection

Introduction:

It is expected that by 2050, the world's population will reach 9.6 billion, which requires large agricultural production to meet their food demands. The agricultural production needs to be increased more than twofold as of now, to increase the production, there are two approaches: first, to increase the area under cultivation and second, to improve the yield from the existing crop population by using different breeding and crop improvement techniques. Moreover, the climatic conditions across the globe are changing rapidly, like the increase in temperature, unseasonal rains, a change in frequency of precipitation and many abnormal climatic phenomena, making crops more vulnerable to biotic and abiotic stresses. To increase the yield, new cultivars need to be used with resistance to all biotic and abiotic stresses to increase yield.

In the second half of the 20th century, backcrossing methods were commercialized, like Marker-assisted backcrossing (MABC), which allowed rapid introgression of key genes representing superior traits into elite cultivars or breeding lines, resulting in cultivars containing both the transgene and the preferred allele (Ragot et al.,1995). Marker-assisted selection (MAS) genetically improves the useful traits in crops. However, marker-assisted selection is limited to a few qualitative traits, which forced the researchers to find an alternative to this technique.

As a result, Genomic Selection (GS) turned into a substitution. It is more reasonable to breed complex traits to which several minor genes are related. Beyond all these techniques, the problem still exists as the population is rapidly increasing, with the reduction of arable land coming together with the vagaries of the climate. To tackle all these complications, AI-driven plant breeding has been hailed as a game-changer in the direction of sustainable agriculture. Creating semi-dwarf, nutrient-responsive responding and hybrid cultivars during the last decade has helped further embrace the green revolution (Bhat et al., 2021).

Artificial Intelligence (AI) in Plant Breeding:

Plant breeding is the science and art of selecting and crossing plants with desirable traits to develop a new plant variety with the desired characteristics and artificial intelligence refers to the incorporation of human intelligence into machines, allowing them to perform tasks requiring human intelligence. The integration of both sciences can help the whole agricultural system to function more efficiently.

Artificial intelligence offers a wide range of services to farmers, including information regarding soil quality, when and what quantity of fertilizer, herbicide and pesticide needs to be applied, weather reports, sowing and harvesting schedules and probable pest infestation and its conservation measures. Further using AI techniques, plant breeding can be advanced with faster use of marker-assisted selection and genomic selection in developing a new plant. The interest of breeders is increasing as artificial intelligence is becoming stable. It collects all the data about the crops that are available in the market in a disaggregated form, arranges them in a systematic pattern and analyzes the vast volume of data quickly using tools that are useful in decision-making in the breeding of a crop.

Application of Artificial Intelligence in Plant Breeding:

1. **Genomic Selection:**
   Artificial intelligence (AI) algorithms can be used to analyze genomic data to predict the performance of a genetic marker linked to the desired character, i.e., disease resistance, salinity tolerance, drought resistance, nutritional values, etc. Therefore, the breeder can easily select plants with the most desired characteristics for subsequent reproduction.
2. **Phenotyping and Trait Selection:**
   Phenotyping refers to the measurement and analysis of the phenotypic traits like the height of the plant, leaf size, leaf area, colour, blooming time and yield potential of the plant by the use of AI-driven remote sensors and imaging systems to observe and analyze the factors helping breeder to produce huge plant population in a short duration (Benos et al., 2021).
3. **Climate Adaptation:**
   Artificial intelligence provides details about the chances of a crop to adapt to various climatic conditions by integrating data inputs about the traits of the crops and their climatic requirements. Hence, this helps the breeder to get an idea of the success and required cultivation practices to grow the crop in an unfamiliar environment.
4. **Predictive Modelling:**
   Artificial intelligence creates models that mimic the plant to different environmental conditions, manifesting their percentage of adaptability. Unlike the conventional methods, the breed is cultivated in different climatic conditions to determine its chances of survival. This reduces both cost and time, simplifying the process of testing various genetic combinations without in-depth field testing.
5. **Disease and Pest Detection:**
   AI can be used to predict disease and pest infestation by analyzing the season and the data collected from nearby farms with disease or pest incidents. This helps in preventing any yield loss and helps in taking timely conservation measures against the same.
6. **Crop Yield Prediction:**
   Machine learning in AI helps in predicting the yield to be achieved from different cultivars after analyzing the factors influencing the crop during its growth period.
7. **Data Interpretation:**
   Artificial intelligence can gather data from multiple sources related to genotype, phenotype, environment, topography, research works, and historical breeding data to facilitate breeders in creating new and successful breeding plans. AI can work on sophisticated relationships between genes, their expression, and environmental factors (Kundu, 2024).

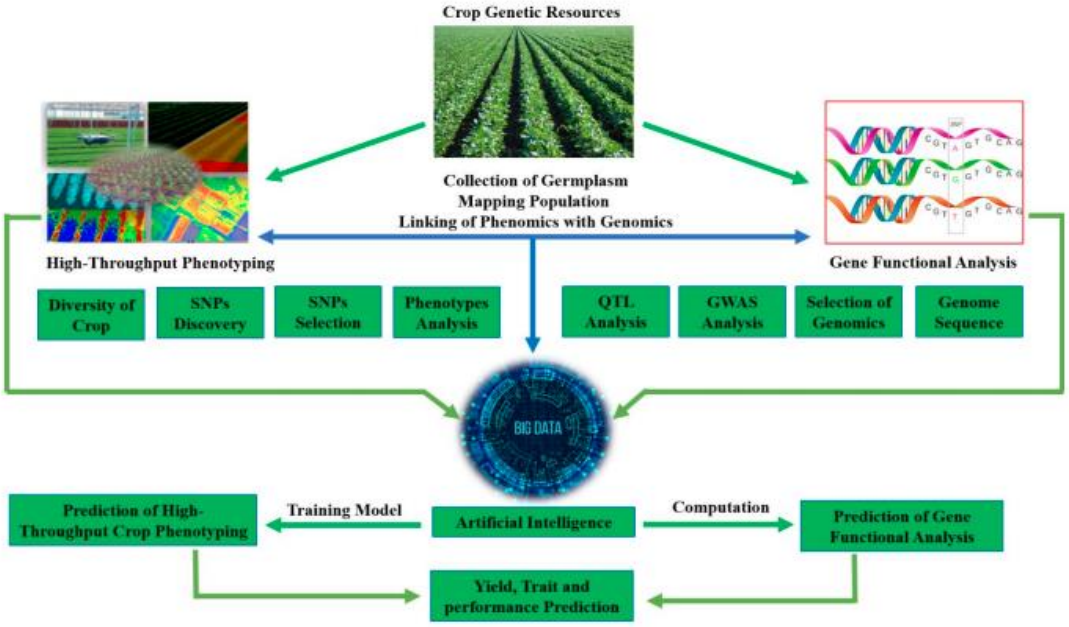

Figure 1. Role of Artificial Intelligence in relating phenotype with genotype (Source: Khan et al., 2022)

8. **Genome Analysis:**
   Artificial intelligence can analyze genome sequences efficiently and accurately, providing breeders with better assembly of DNA sequences and error correction, making genetic sequencing a faster and more reliable process (Krishna et al., 2024).

Use of Machine Learning for Genome Sequencing:

Machine Learning (ML) is the process used by artificial intelligence where data and information are collected without explicitly programming them. ML takes samples and forms a model, comparing with the current data and makes predictions. This is highly flexible and can adapt to a wide range of complex

associations between input and output. It is difficult to build a database of genomics, inherent complexities and environmental variability and with this, the use of machine learning AI can be a good alternative (Jeon et al., 2023).

Benefits of the use of AI in Plant Breeding:

- With the use of AI, the duration of breeding and developing a cultivar is reduced by many folds. It reduces the breeding cycle and speeds up the analysis of genetic information and the prediction of crop types. It accelerates the breeding process as a whole.
- It provides a collaborative platform to share data between the breeders, researchers and farmers across different parts of the country.
- Provides precise information about the behaviors resulting from different genetic combinations.
- Brings precision and accuracy in breeding, i.e., identifying target genes and anticipating the effects of particular genetic alterations, which enables scientists to pinpoint modifications of the requirement.
- AI can automate the labour-intensive and repetitive processes involved in plant breeding, reducing time and cost (Sampath et al.,2023)

Drawbacks of AI in Plant Breeding:

- Lack of domain experts, as operating AI requires expertise to provide proper factors and parameters to be analyzed to generate outcomes.
- The establishment and maintenance of artificial intelligence systems requires a huge investment. In India, we mostly have multiple small breeding farms for which such large investments are not feasible.
- AI predictions mostly depend on data available, for a country like India with dynamic climatic conditions and frequent weather changes, the data needs to be renewed frequently. Therefore, the quality of data needs to be changed repeatedly.
- It raises many legal and ethical issues, as the result of any genetic modification or impact of any variety could conflict with the pre-existing breeding regulations.

Further Suggestions:

There has been a significant increase in the use of artificial intelligence in each sector to ease the work, accompanied by efficiency and precision. The use of AI in agriculture is a recent development, still it is predicted to increase by 25.4% in the next 5-6 years. Automating the breeding procedures by statistical and algorithmic analysis by AI guarantees accuracy and saves time, but this process should not be a replacement for conventional methods, as artificial intelligence is still in its early stages. It still has many drawbacks, where the conventional methods to take reviews from farmers, experimenting with changing climatic conditions, and maintaining legal and ethical values are done more effectively. Therefore, modernizing the plant breeding industry requires creating an equilibrium between AI and conventional methods to move toward sustainability in agriculture.

Conclusion

In conclusion, the incorporation of AI in plant breeding has been a major step in bringing sustainability to agriculture. Artificial intelligence has helped in the selection of desired parents and developing desired cultivars in a short duration. Post introduction, AI has been extensively used in the selection of desired traits, breeding decisions, adaptability to various climatic conditions and predicting crop performance with never-before precision and efficiency. AI has been successfully integrating enormous volumes of phenotypic and genotypic traits. The current scenario, where the population is increasing dramatically, and their food requirements in this changing climate, requires a technological revolution in the agricultural sector, which can be facilitated through the use of AI in crop improvement. It is required that AI must be used ethically to safeguard privacy, equity and sustainability. The prospects of AI in crop breeding have enormous potential to innovate and expand all over the world. Therefore, when properly utilized, artificial intelligence in plant breeding has the potential to help the world achieve its sustainability goals in agriculture.

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