Asian Jr. of Microbiol. Biotech. Env. Sc. Vol. 25, No. (4) : 2023 : 629-632
© EM International
ISSN-0972-3005

DOI No.: http://doi.org/10.53550/AJMBES.2023.v25i04.003

DIGITAL REVOLUTION IN PLANT BREEDING: A COMPREHENSIVE REVIEW OF METHODOLOGIES, TOOLS, APPLICATIONS, AND FUTURE PERSPECTIVES

S.N.K. REDDY[1], PUNEET WALIA[2] AND SANJEET SINGH SANDAL[3]

Department of Genetics and Plant Breeding, School of Agriculture, Lovely Professional University, Phagwara 144 411, Punjab, India

(Received 13 April, 2023; Accepted 18 June, 2023)

Key words : *Genomics, Bioinformatics, Conventional breeding, Multiple omics technologies*

Abstract– Digital breeding integrates modern technologies like genomics, bioinformatics, and data analytics into conventional plant breeding. It accelerates the breeding process, improves selection effectiveness, and enhances crop yield and quality. High-throughput genotyping and phenotyping technologies enable efficient analysis of large populations and rapid characterization of plant traits. Genomic selection and data analytics aid in predicting breeding values and analyzing extensive data for trait improvement. Digital breeding applications include accelerated breeding cycles, trait-based breeding, disease resistance, stress tolerance, nutritional quality enhancement, remote sensing, yield prediction, multi-environment testing, and precision breeding and prospects involve integrating multiple omics technologies, developing precise phenotypic prediction models, and fostering data sharing and collaboration. Digital breeding can greatly improve breeding programs and address global food security challenges.

INTRODUCTION

Digital breeding, also called computational breeding or virtual breeding, involves the incorporation of modern technologies like genomics, bioinformatics, and data analytics into conventional methods of plant breeding(Xu and Crouch, 2008). It utilizes computer-based tools and algorithms to expedite the breeding process, increase selection effectiveness, and enhance the overall yield and quality of cultivated crops (Razzaq *et al.*, 2021). In recent years, there has been a notable surge in interest and recognition of digital breeding, primarily due to its immense potential to transform the field of plant breeding and effectively tackle the pressing issues related toglobal food security (Godfray *et al.*, 2010). In this response, we will explore the advancements, applications, and future perspectives of digital breeding.

Methodologies and Tools in Digital Breeding

Genotyping Technologies: The advent of high-throughput genotyping technologies, such as single nucleotide polymorphism (SNP) arrays and next-generation sequencing, has revolutionized the field of breeding. These technologies enable breeders to genotype large numbers of individuals efficiently and cost-effectively, allowing for the identification of genetic markers associated with desired traits (Bhat *et al.*, 2016).

High-Throughput Phenotyping Technologies

High-throughput phenotyping technologies, such as remote sensing, imaging, and sensor-based platforms, have advanced digital breeding by enabling non-destructive and rapid characterization of plant traits. These technologies provide detailed phenotypic data, allowing breeders to identify desirable traits and assess the performance of a large number of plants efficiently. Examples of high-throughput phenotyping techniques include hyperspectral imaging (Zhang *et al.*, 2018), unmanned aerial vehicles (UAVs) (Araus and Cairns, 2014), and automated sensor networks (Furbank and Tester, 2011).

Genomic Selection: Genomic selection is a key advancement in digital breeding that involves the use of high-throughput genotyping and

([1]Masters Student, [2]Assistant Professor, [3]Assistant Professor) phenotyping data to predict the breeding value of plants. This technique allows breeders to select superior individuals based on their genomic profiles, leading to more accurate and efficient selection. Genomic selection has been successfully applied in various crops, including maize (Crossa *et al.,* 2017), rice (Spindel *et al.,* 2015), and wheat (Vidotti *et al.,* 2019).

Data Analytics: Digital breeding generates vast amounts of data from genomics, phenomics, and environmental variables. Big data analytics, including machine learning and data mining techniques, are crucial for handling and extracting useful information from these datasets. By analyzing large datasets, breeders can identify genomic regions associated with important traits, uncover complex trait interactions, and develop predictive models for trait improvement. Big data analytics have been applied in crop breeding studies, such as predicting yield in wheat (Montesinos-Lopez *et al.,* 2017) and identifying genetic markers for disease resistance in soybean (Bisht*et al.,* 2023).

Applications of Digital Breeding

Accelerated Breeding Cycles: Digital breeding facilitates the acceleration of breeding cycles by reducing the time required for trait evaluation and selection. By integrating genomic selection and high-throughput phenotyping, breeders can identify promising individuals at early stages and make informed selection decisions. This approach has been applied in various crops, such as maize soybean (Rolling *et al.,* 2020), and tomato (Samantara *et al.,* 2022), leading to shortened breeding cycles and faster release of improved varieties.

Trait-Based Breeding: Digital breeding enables a shift from traditional phenotype-based breeding to trait-based breeding. By leveraging genomic information and advanced phenotyping technologies, breeders can focus on specific traits of interest, such as disease resistance, drought tolerance, or nutritional quality. This targeted approach allows breeders to develop varieties with improved performance in specific environments or tailored to meet specific market demands. Trait-based breeding has been successfully employed in crops like wheat (Araus *et al.,* 2008), potato (Tiwari *et al.,* 2022).

Disease Resistance and Stress Tolerance: Digital breeding plays a crucial role in developing crops and livestock with enhanced disease resistance and stress tolerance. By analyzing genomic data, breeders can identify genes and pathways associated with resistance to pests, pathogens, and abiotic stresses. This knowledge enables the development of breeding strategies aimed at improving crop and livestock resilience to environmental challenges (Hu and Xiong, 2014).

Nutritional Quality Enhancement: Digital breeding contributes to enhancing the nutritional quality of crops and livestock products. By understanding the genetic basis of nutritional traits, breeders can select individuals with improved nutritional profiles, such as increased vitamin content, improved fatty acid composition, or reduced allergenicity. Digital breeding also enables precision breeding for functional food production (Gatica-Arias, 2020).

Remote Sensing and Drones: Remote sensing technologies, including aerial and satellite imagery, coupled with unmanned aerial vehicles (UAVs) or drones, offer a cost-effective and efficient means to monitor crop growth and assess field conditions. These tools provide breeders with spatial and temporal information about plant health, stress response, and growth patterns, enabling targeted breeding strategies (Yang *et al.,* 2020).

Yield Prediction and Optimization: Digital breeding techniques can be used to predict crop yield based on plant phenotypes and environmental conditions. This information can help breeders optimize agronomic practices and develop varieties with improved yield potential (Montesinos-Lopez *et al.,* 2017).

Multi-Environment Testing: Digital breeding facilitates multi-environment testing, where breeders evaluate the performance of plant materials across diverse environments. Byanalyzing large datasets of genotype-by-environment interactions, breeders can identify stable and adaptable varieties that perform well across different growing conditions. This approach is particularly valuable for addressing the challenges posed by climate change and ensuring the resilience and adaptability of crop plants. Multi-environment testing has been utilized in crops like rice (Spindel *et al.,* 2015), barley (Maldonado *et al.,* 2022), and cotton (Gapare *et al.,* 2018).

Precision Breeding and Genome Editing: Digital breeding integrates with genome editing technologies, such as CRISPR-Cas9, to achieve precise modifications in the genetic makeup of plants and animals. This approach enables breeders to introduce or modify specific traits rapidly. Digital breeding platforms can assist in identifying target genes for genome editing, optimizing editing efficiency, and assessing the potential impacts of edited traits (Varshney *et al.,* 2021).

Future Perspectives of Digital Breeding

Integration of Omics Technologies: The integration of multiple -omics technologies, such as genomics, transcriptomics, metabolomics, and proteomics, holds great potential for advancing digital breeding. By combining data from different molecular levels, breeders can gain a deeper understanding of the underlying biological processes, identify key genes and pathways, and develop more precise selection strategies. The integration of omics technologies has been explored in crops like chickpea (Singh *et al.*, 2023), soybean (Bisht *et al.*, 2023), and wheat (Ros *et al.,* 2023).

Phenotypic Prediction Models: Developing accurate and reliable phenotypic prediction models is a key focus of future digital breeding efforts. By combining genomic data with advanced statistical and machine learning algorithms, breeders aim to predict complex traits that are difficult or expensive to measure directly. Improving the accuracy of phenotypic prediction models will enhance selection efficiency and enable more effective identification of superior genotypes. Ongoing research in this area includes the use of deep learning algorithms (Xu *et al.,* 2021).

Data Sharing and Collaboration: The future of digital breeding relies on increased data sharing and collaboration among breeders, researchers, and institutions. Open data platforms, standardized protocols, and collaborative networks are essential for maximizing the potential of digital breeding. By sharing data, breeders can build larger and more diverse datasets, improve the robustness of prediction models, and accelerate variety development. Initiatives such as the Integrated Breeding Platform (https://www.integratedbreeding.net/) and the CGIAR Excellence in Breeding Platform (https://excellenceinbreeding.org/) are examples of collaborative efforts in digital breeding.(Rasheed *et al.,* 2017).

CONCLUSION

Digital breeding has witnessed significant advancements and offers numerous applications and future perspectives for plant breeding. The integration of genomic selection, high-throughput phenotyping, and big data analytics has accelerated breeding cycles, enabled trait-based breeding, and facilitated multi-environment testing. The future of digital breeding lies in the integration of omics technologies, the development of accurate phenotypic prediction models, and increased data sharing and collaboration. These advancements and future directions hold great promise for improving the efficiency, precision, and sustainability of plant breeding efforts worldwide.

REFERENCES

Araus, J. L., Slafer, G.A., Royo, C. and Serret, M.D. 2008. Breeding for yield potential and stress adaptation in cereals. *Critical Reviews in Plant Science. 27*(6): 377-412.

Araus, J.L. and Cairns, J.E. 2014. Field high-throughput phenotyping: the new crop breeding frontier. *Trends in Plant Science.* 19(1): 52-61.

Bhat, J.A., Ali, S., Salgotra, R.K., Mir, Z.A., Dutta, S., Jadon, V. and Prabhu, K. 2016. Genomic selection in the era of next generation sequencing for complex traits in plant breeding. *Frontiers in Genetics.* 7: 221.

Bisht, A., Saini, D. K., Kaur, B., Batra, R., Kaur, S., Kaur, I., and Siddique, K.H. 2023. Multi-omics assisted breeding for biotic stress resistance in soybean. *Molecular Biology Reports*. 50(4): 3787-3814.

Crossa, J., Pérez-Rodríguez, P., Cuevas, J., Montesinos-López, O., Jarquín, D., De Los Campos, G. and Varshney, R.K. 2017. Genomic selection in plant breeding: methods, models, and perspectives. *Trends in Plant Science.* 22(11): 961-975.

Da Ros, L., Bollina, V., Soolanayakanahally, R., Pahari, S., Elferjani, R., Kulkarni, M. and Kagale, S. 2023. Multiomics atlas of combinatorial abiotic stress responses in wheat. *The Plant Journal*.

Furbank, R.T. and Tester, M. 2011. Phenomics - technologies to relieve the phenotyping bottleneck. *Trends in Plant Science*. 16(12): 635-644.

Gapare, W., Liu, S., Conaty, W., Zhu, Q.H., Gillespie, V., Llewellyn, D. and Wilson, I. 2018. Historical datasets support genomic selection models for the prediction of cotton fiber quality phenotypes across multiple environments. *G3: Genes, Genomes, Genetics.* 8(5): 1721-1732.

Gatica-Arias, A. 2020. The regulatory current status of plant breeding technologies in some Latin American and the Caribbean countries. *Plant Cell, Tissue and Organ Culture (PCTOC).* 141(2): 229-242.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F. and Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. *Science.* 327(5967): 812-818.

Hu, H. and Xiong, L. 2014. Genetic engineering and breeding of drought-resistant crops. *Annual Review* *of Plant Biology.* 65: 715-741.

Maldonado, J.G. 2022. *Genomic-assisted sparse multi-location testing to increase genetic gains in barley* (Doctoral dissertation, International Center for Agricultural Research in the Dry Areas).

Montesinos-López, O.A., Montesinos-López, A., Crossa, J., de Los Campos, G., Alvarado, G., Suchismita, M. and Burgueño, J. 2017. Predicting grain yield using canopy hyperspectral reflectance in wheat breeding data. *Plant Methods.* 13: 1-23.

Rasheed, A., Hao, Y., Xia, X., Khan, A., Xu, Y., Varshney, R.K. and He, Z. 2017. Crop breeding chips and genotyping platforms: progress, challenges, and perspectives. *Molecular Plant.* 10(8): 1047-1064.

Razzaq, A., Kaur, P., Akhter, N., Wani, S. H. and Saleem, F. 2021. Next-generation breeding strategies for climate-ready crops. *Frontiers in Plant Science*. 12: 620420.

Rolling, W.R., Dorrance, A.E. and McHale, L.K. 2020. Testing methods and statistical models of genomic prediction for quantitative disease resistance to Phytophthora sojae in soybean [*Glycine max* (L.) Merr] germplasm collections. *Theoretical and Applied Genetics.* 133(12): 3441-3454.

Samantara, K., Bohra, A., Mohapatra, S. R., Prihatini, R., Asibe, F., Singh, L. and Varshney, R.K. 2022. Breeding more crops in less time: A perspective on speed breeding. *Biology.* 11(2): 275.

Singh, V., Gupta, K., Singh, S., Jain, M. and Garg, R. 2023. Unravelling the molecular mechanism underlying drought stress response in chickpea via integrated multi-omics analysis. *Frontiers in Plant Science*. 14.

Spindel, J.E., Begum, H., Akdemir, D., Collard, B., Redoña, E., Jannink, J.L. and McCouch, S. 2016. Genome-wide prediction models that incorporate de novo GWAS are a powerful new tool for tropical rice improvement. *Heredity.* 116(4): 395-408.

Spindel, J., Begum, H., Akdemir, D., Virk, P., Collard, B., Redona, E. and McCouch, S. R. 2015. Genomic selection and association mapping in rice (*Oryza sativa*): effect of trait genetic architecture, training population composition, marker number and statistical model on accuracy of rice genomic selection in elite, tropical rice breeding lines. *PLoS Genetics.* 11(2): e1004982.

Tiwari, J. K., Buckseth, T., Zinta, R., Bhatia, N., Dalamu, D., Naik, S. and Kumar, M. 2022. Germplasm, breeding, and genomics in potato improvement of biotic and abiotic stresses tolerance. *Frontiers in Plant Science.* 13: 163.

Varshney, R. K., Bohra, A., Roorkiwal, M., Barmukh, R., Cowling, W.A., Chitikineni, A. and Siddique, K.H. 2021. Fast-forward breeding for a food-secure world. *Trends in Genetics.* 37(12): 1124-1136.

Vidotti, M.S., Matias, F.I., Alves, F.C., Pérez-Rodríguez, P., Beltran, G.A., Burgueño, J. and Fritsche-Neto, R. 2019. Maize responsiveness to Azospirillum brasilense: Insights into genetic control, heterosis and genomic prediction. *PloS One.* 14(6): e0217571.

Xu, Y. and Crouch, J.H. 2008. Marker assisted selection in plant breeding: From publications to practice. *Crop Science.* 48(2): 391-407.

Xu, Y., Ma, K., Zhao, Y., Wang, X., Zhou, K., Yu, G. and Xu, S. 2021. Genomic selection: A breakthrough technology in rice breeding. *The Crop Journal.* 9(3): 669-677.

Yang, G., Liu, J., Zhao, C., Li, Z., Huang, Y., Yu, H. and Huang, D. 2020. Unmanned aerial vehicle remote sensing for field-based crop phenotyping: current status and perspectives. *Frontiers in Plant Science.* 11: 261.

Zhang, Y. and Zhang, N. 2018. Imaging technologies for plant high-throughput phenotyping: a review. *Frontiers of Agricultural Science and Engineering*. 5(4): 406-419.