THE SCIENCE WORLD
A Monthly e Magazine
ISSN:2583-2212

Popular Article

November 2024 Vol.4(11), 5148-5157

Novel Strategies for Breeding Climate Resilient Crops

Anupam Tripathi, Priyanka Jaiswal, Deepak Kumar Prajapati, Javed, Laxmidas verma, Vinod Kumar Singh*

Department of Genetics & Plant Breeding, A.N.D.U.A. &T., Kumarganj, Ayodhya, (U.P) - 224229.

Abstract

The development of climate-resilient crops through novel breeding strategies such as genome editing, Speed breeding etc. offers significant potential for addressing the challenges posed by climate change. Technological advancements present promising solutions; Global initiatives by organizations like FAO and CGIAR aid conservation efforts, while national gene centers preserve emerging trends in unique crop varieties however, they introduce ethical considerations and potential risks that must be carefully managed. Achieving a balance between innovation, ethical responsibility, and environmental sustainability is critical. In this evolving field, establishing robust regulatory frameworks, fostering transparent communication, and ensuring fair access to benefits will be essential. Ultimately, the integration of these strategies is key to building a resilient, ethical, and equitable agricultural future in response to global climate change.

1.Introduction

The global challenge of food security is highlighted by the increasing world population. Achieving a hunger-free world depends on sustainable growth in agricultural productivity. Currently, around two billion people face severe micronutrient deficiencies, with over 815million experiencing chronic hunger. Developing regions in Western Asia and Africa have seen a rise in undernourished populations since 2014 (FAO, 2018). Novel strategies for breeding climate-resilient crops have become imperative in the face of increasing environmental challenges.The situation is exacerbated by the impact of SARS-CoV-2 on the food supply chain, further threatening global food security. With climate change influencing temperature patterns, water availability, and the prevalence of pests and diseases, traditional breeding methods are proving insufficient. Scientists are employing advanced technologies such as genomic selection, marker-assisted breeding, and CRISPR-Cas9 gene editing and speed breeding technology to accelerate the development of crops with enhanced resilience to biotic and abiotic stresses.These approaches enable the identification and incorporation of specific genes associated with traits like drought tolerance, heat resistance, and disease immunity. Additionally, precision agriculture techniques, including remote sensing and data analytics, aid in monitoring and selecting crops that performs well under changing climatic conditions. These innovative strategies not only streamline the breeding process but also hold the key to ensuring global food security in the face of a dynamic and uncertain climate.

2. Understanding Climate Resilience in Crops:

Climate resilience in crops refers to the ability of plants to withstand and adapt to the adverse impacts of climate change, including rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events. Key characteristics of climate-resilient crops include tolerance to temperature variations, improved water-use efficiency, resistance to pests and diseases, and the capacity to thrive in diverse environmental conditions. As climate change increasingly affects traditional crop varieties, their susceptibility to new challenges rises. The impact encompasses reduced yields, compromised nutritional content, and heightened vulnerability to pests and diseases. Recognizing the critical importance of global food security, there is a growing emphasis on developing crops that exhibit resilience to these changing climatic conditions. This involves employing advanced breeding techniques, such as genetic modification and precision agriculture, to enhance the adaptive capacity of crops and ensure a sustainable and resilient agricultural future.

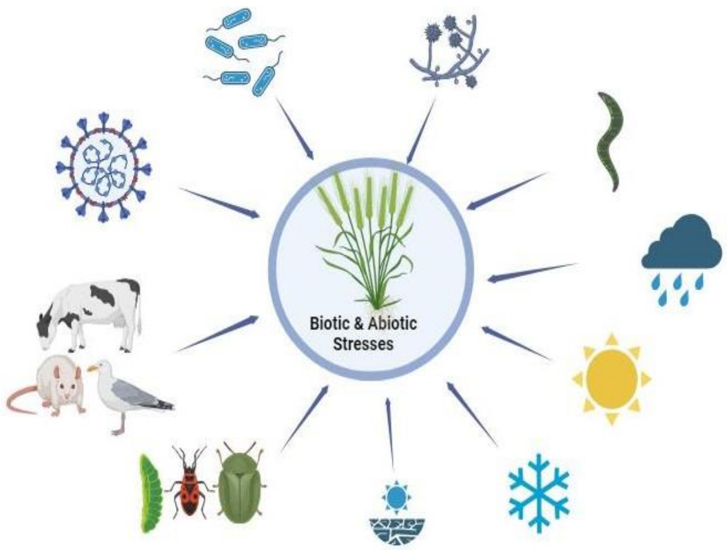

Fig-1 Various Biotic and Abiotic Stresses of plant

Official Website
www.thescienceworld.net
thescienceworldmagazine@gmail.com
Published 22/11/2024

3. Novel Strategies in Crop Breeding

Novel strategies for breeding for climate resilient crops are those that use advanced technologies and methods to enhance the adaptability and stability of crop varieties under changing and unpredictable environmental conditions. Some of these strategies are:

3.1 Genomic-assisted breeding (GAB):

Genomic-assisted breeding (GAB) is a transformative approach in agriculture that harnesses molecular markers and genomic data to expedite the identification and selection of desirable traits in crop plants. By focusing on specific genetic markers associated with traits such as drought tolerance, heat tolerance, disease resistance, and others, GAB enables a targeted and precision-driven breeding process. This methodology significantly enhances the accuracy and efficiency of trait selection compared to traditional breeding methods.The core principle of GAB lies in understanding the genetic makeup of crop plants at the molecular level. Researchers can pinpoint the genes responsible for key agronomic traits and then develop molecular markers that act as indicators for these traits.These markers serve as genetic signposts, allowing breeders to quickly and accurately assess whether a plant possesses the desired characteristics.

One of the key advantages of GAB is its ability to accelerate the breeding process. Traditional breeding methods often require several generations of plants to achieve the desired trait combinations. GAB expedites this process by enabling breeders to directly select plants with the desired traits at the molecular level, reducing the time it takes to develop new crop varieties.

Moreover, GAB enhances the precision of trait selection. Traditional methods rely on the observation of phenotypic traits, which can be influenced by environmental factors and may take time to manifest. GAB, on the other hand, allows breeders to identify desirable traits at the genetic level, providing a more accurate and reliable means of selection.

The integration of GAB with other advanced technologies, such as high-throughput phenotyping, artificial intelligence, and machine learning, forms a powerful synergy in modern crop improvement programs. This comprehensive approach not only expedites the breeding process but also ensures that the selected crop varieties exhibit resilience and high performance under specific stress conditions, contributing to the development of crops that can address the challenges posed by a changing climate and other environmental stressors. In essence, GAB represents a paradigm shift in crop breeding, offering a potent tool to enhance agricultural sustainability, improve food security, and meet the demands of a growing global population.

Official Website
www.thescienceworld.net
thescienceworldmagazine@gmail.com

Published 22/11/2024

This involves using molecular markers and genomic data to identify and select desirable traits in crop plants, such as drought tolerance, heat tolerance, disease resistance, etc. GAB can accelerate the breeding process and increase the accuracy and efficiency of selection1.

3.2 Genome editing

This involves using tools such as CRISPR/Cas systems to precisely modify the DNA sequence of crop plants, introducing or removing specific genes or mutations that affect their performance under stress conditions12. Genome editing can create novel genetic variation and improve the quality and yield of crops

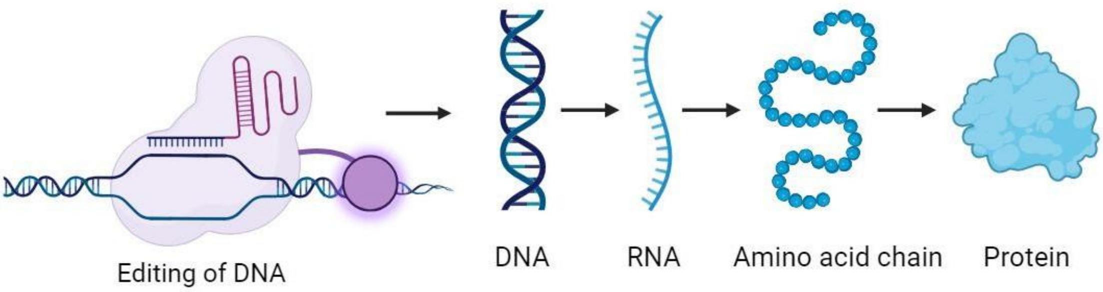

Fig.2: **Genome editing using CRISPR- Cas-9**

3.3 Speed breeding:

Speed breeding is an innovative and strategic approach in agriculture that harnesses controlled environments, such as greenhouses or growth chambers, to revolutionize traditional breeding timelines. The primary objective is to shorten the crop life cycle, enabling multiple generations per year. This accelerated breeding technique has gained prominence for its potential to rapidly screen and evaluate large populations of crop plants, especially for stress tolerance and other desirable traits.

3.3.1. Principles of Speed Breeding

1. **Controlled Environments:** Greenhouses and growth chambers provide precise control over environmental variables, including temperature, humidity, and lightconditions. This control allows for the manipulation of the growing environment to optimize conditions for accelerated plant growth.
2. **Extended Photoperiods:** Speed breeding often involves the use of extended photoperiods using artificial lighting systems. This extended exposure to light stimulates continuous growth

Official Website
www.thescienceworld.net
thescienceworldmagazine@gmail.com
Published 22/11/2024

and development, effectively reducing the time requiredfor a plant to reach maturity.

3. **Continuous Harvesting:** Unlike traditional field conditions where crops follow a seasonal cycle, speed breeding allows for continuous harvesting throughout the year. This continuous production model significantly increases the number of generations that can be achieved annually.

Speed breeding provides an efficient platform for the rapid screening of large populations of crops, facilitating the identification of stress-tolerant varieties.

3.3.2. Applications of Speed breeding beyond Crop Improvement

- Genetic Mapping Populations
- Genetic Modification (GM) Crop Development
- Trait Stacking for Resilient Crop Varieties
- Enhancing Research across Disciplines

Table: 1. List of crops standardized through speed breeding technique

Crop	Speed Breeding Conditions	nerationTime	Number of Generations perYear
Soybean	10 h. photoperiod (Blue light enriched) and use of light-emitting diodes (LEDs).	77	5
Peanut	24 h. light and 28 ± 3 °C max. 17 ± 3 °C min. temperature.	89	4
Pea	20 h. photoperiod, 21 °C/16 °C light/dark temp., 500 μM m^{-2} s^{-1} light intensity and hydroponic system.	68.4	5.3
Chickpea	light, (25 ± 1) °C temperature and immature seed harvest.	50–52.7 in early maturing accessions 55.4–58.6 in medium maturity accessions	7, 6.2 and 6 in early, medium, and late maturity accessions

Official Website
www.thescienceworld.net
thescienceworldmagazine@gmail.com

Published 22/11/2024

Wheat	22 h. light, 22/17 °C temperature and immature seed harvest.	65.4	5.6
Canola	22 h. light, 22/17 °C temperature and immature seed harvest.	98.2	3.7
Barley	22 h. light, 22/17 °C temperature and immature seed harvest.	68.4	5.3
Canola	20 h. photoperiod, 25/22 (±1) °C.	62–71	5.1–5.9
Winter wheat	22 h. light, 25 °C/22 °C temperature.	87	4
Faba bean	20 h. photoperiod, 21 °C light/16 °Cdark temperature, 10–5 M BAP application.	89	4
Lentil	20 h. photoperiod, 100 µM gibberellin application and immature seed harvest.	56	5
Oat, Triticale	20 h. photoperiod, 25/22 °C day/night temperature, 65/85% day/night RH, In vitro culture of immature embryos.	41–61	6–7.6
Oat	22 h. photoperiod, 20/16 °C.	51	5
Cowpea	11-day-old pod seeds oven-dried at 39 °C.	-	8
Pigeon pea	2870–2900 rpm and a blower wheel delivering air @ 2980–9330 m^3/h. 28–32 °C.	50–56	4

Source: Potts et al., 2023

This is particularly crucial in the face of climate change, where crops need to withstand varying environmental conditions. Traditional breeding methods can be time-consuming, often requiring several years to develop a new crop variety. Speed breeding expedites thebreeding process, enabling researchers to introduce new traits and characteristics into crops at a much faster rate. The ability to cycle through multiple generations in a short time allows for the exploration of a broader range of genetic diversity. This diversity is essential for introducing novel traits and enhancing the overall resilience of crops.

Official Website
www.thescienceworld.net
thescienceworldmagazine@gmail.com

Published 22/11/2024

3.4 High-throughput phenotyping (HTP):

High-throughput phenotyping (HTP) is a revolutionary approach in agriculture that leverages automated or remote sensing devices, including drones, cameras, and various sensors, to systematically measure and record the physical and physiological characteristics of crop plants. These characteristics encompass a wide range of parameters such as biomass, leaf area, chlorophyll content, water use efficiency, and more. HTP enables researchers to collect vast amounts of data efficiently and non-invasively, providing a detailed understanding of how different genotypes respond to various stress conditions.

The integration of artificial intelligence (AI) and machine learning (ML) plays a pivotal role in making sense of the extensive datasets generated through HTP. These advanced technologies facilitate the analysis of complex patterns within the data, allowing for the identification of the best-performing genotypes under stress. AI and ML algorithms can discern subtle correlations and trends that may be challenging for traditional analytical methods to uncover.

By employing HTP in combination with AI and ML, researchers can expedite the breeding process by selecting and advancing crop varieties that exhibit superior resilience and performance under specific environmental stressors. This not only enhances the efficiency of crop improvement programs but also contributes to the development of climate-resilient crops that are better equipped to address the challenges posed by factors such as climate change, diseases, and resource limitations. In essence, HTP, coupled with advanced data analysis techniques, represents a cutting-edge strategy that holds significant promise for revolutionizing crop breeding and ensuring global food security inthe face of a growing population and changing environmental conditions.

			OaUxoC7DwQAvD_BwE
Tree Phenotyping Platform (TPP)	Sweden	Umea University	https://www.upsc.se/tree-phenotyping-platform-at-upsc.html
PHENOME-French Plant Phenotyping Network (FPPN)	France	INRA	https://www6.angers-nantes.inrae.fr/bia_eng/BIA-highlights/ Major-projects/PHENOME

Official Website
www.thescienceworld.net
thescienceworldmagazine@gmail.com

Published 22/11/2024

Table -1 list of major High-Throughput Phenotyping Facilities Worldwide

Phenotyping system	Country	University/Institute/Collaboration	Weblink
International Plant Phenotyping Network (IPPN)	Different partner countries	-	https://www.plant-phenotyping.org/
European Plant Phenotyping Network 2020 (EPPN)	Collaboration of 22 European countries	-	https://eppn2020.plant-phenotyping.eu/EPPN2020_start
WSU Plant Phenomics	United States	Washington State University	http://phenomics.cahnrs.wsu.edu/
Nebraska Innovation Campus (NIC)	United States	University of Nebraska-Lincoln	https://ard.unl.edu/phenotyping/nebraska-innovation-campus greenhouse
Center for Advanced Algal and Plant Phenotyping	United States	Michigan State University	https://prl.natsci.msu.edu/research-tech/center-for-advanced-algal-and-plant-phenotyping/
Austrian Plant Phenotyping Network (APPN)	Austria (Vienna BioCenter)	University of Innsbruck, University of Vienna, University of Natural Resources and Life Sciences	https://appn.at/plant-phenotyping-forum/
Australian Plant Phenomics Facility (APPF)	Australia	Australian National University, The University of Adelaide, Commonwealth Scientific and Industrial Research Organization (CSIRO)	https://www.plantphenomics.org.au/
McGill Plant Phenomics Platform (MP3)	Canada	McGill University	http://mustang.biol.mcgill.ca/mcgill_mp3_summary.ht
Eastern Canadian Plant Phenotyping Platform (ECP3)	Canada	McGill University	https://www.mcgill.ca/macdonald/research/canada-foundation- innovation-grants/eastern-canadian-plant-

			phenotyping-platform ecp3
Jülich Plant Phenotyping Centre (JPPC)	Germany	Jülich Forschungszentrum	https://www.fz-juelich.de/ibg/ibg-2/EN/_organisation/JPPC/JPPC_node.html
Plant Growth Facility (PGF)	United Kingdom	Cranfield University	https://www.cranfield.ac.uk/facilities/plant-growth-facility
National Plant Phenomics Centre (NPPC)	United Kingdom	Aberystwyth University	https://www.plant-phenomics.ac.uk/
National Plant Phenotyping Infrastructure (NaPPI)	Finland	University of Helsinki and University of Eastern Finland	https://www.helsinki.fi/en/infrastructures/national-plant-phenotyping
Nordic Plant Phenotyping Network (NPPN)	Denmark	University of Copenhagen	https://nordicphenotyping.org/
Netherlands Plant Eco- phenotyping Centre (NPEC)	Netherlands	Wageningen University & Research and Utrecht University	https://www.worldfoodinnovations.com/activities/facilities/hetherlands-plant-eco-phenotyping-centre
Czech Plant Phenotyping Network (CZPPN)	Czech Republic	Palacky University Olomouc	http://www.czppn.com/
Phenome Networks	Israel	-	https://phenome-networks.com/es/
Weighing, Imaging & Watering Machines (WIWAM)	Belgium	-	https://www.wiwam.be/?gclid=CjwKCAjw-YT1BRAFEiwAd2WRtqXp5W2FVAAYMBGYTqM_oAonzekRfhxkX7ZmSK3MHWMBmjg4E-

3.5 Artifecial Intelligence (AI) in Plant Breeding

Artificial Intelligence (AI) in agriculture has revolutionized traditional methods by leveraging advanced technologies to enhance efficiency and productivity. Through the integration of machine learning algorithms, data analytics, and sensor technologies, AI enables Breeders to make data-driven decisions for crop management, irrigation, and pest control. Smart farming systems powered by AI can analyze vast amounts of data from various sources, such as weather patterns, soil conditions, and crop health, providing valuable insights to optimize resource allocation and improve yields. Additionally, AI-driven robotics and drones contribute to precision agriculture, performing tasks like planting, harvesting, and monitoring fields with unprecedented accuracy. This convergence of technology and agriculture not only increases productivity but also promotes sustainable and environmentally friendly practices, ensuring a more resilient and efficient future for the agricultural sector.

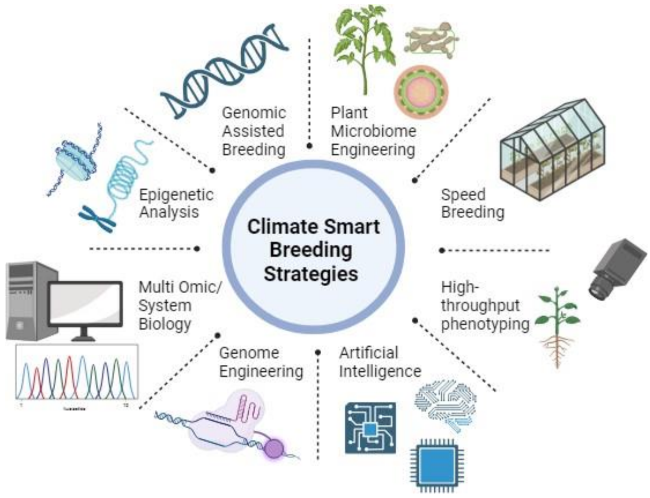

Fig: 3 Various Strategies for Climate Smart Breeding.

4. Challenges and Ethical Considerations:

The adoption of novel breeding strategies for climate-resilient crops poses challenges andethical concerns. Unintended ecological consequences, potential risks of genetic modifications, and questions about equitable access to advanced technologies are key challenges. Ethical considerations involve the responsible use of tools like CRISPR-Cas9, addressing public concerns, and ensuring transparent communication. Environmental impacts, such as increased chemical usage, must be carefully managed. Balancing innovation with ethical responsibility requires stringent regulations, promoting sustainability, and fair distribution of benefits. Navigating these challenges is crucial for aresilient and ethical future in global agriculture. Global Collaborations and Initiatives.

5. Future Outlook

Climate-resilient crop breeding is characterized by promising trends and ongoing advancements that hold significant implications for global food security and sustainable agriculture. Emerging trends include the integration of cutting- edge technologies such as artificial intelligence, machine learning, and precision agriculture in breeding programs. These innovations enable more precise identification and manipulation of genes associated with climate resilience, accelerating the development of resilient crop varieties.

These advancements have the potential to revolutionize agricultural practices, fostering increased yields, reduced resource usage, and improved resilience in the face of climate variability. As a result, global food security could see substantial improvements, with crops better equipped to withstand changing climate conditions and contribute to sustainable agricultural practices.

References:

Razzaq A, Kaur P, Akhter N, Wani SH and Saleem F (2021) Next-Generation Breeding Strategies for Climate-Ready Crops. *Front. Plant Sci.* 12:620420. doi: 10.3389/fpls.2021.620420

FAO. (2018). *The* State of Food Security and Nutrition in the World *2018: Building Climate Resilience for Food Security and Nutrition*. Rome: Food & Agriculture Org.

Henry, R. (2020). Innovations in agriculture and food supply in response to the COVID-19 pandemic. *Mol. Plant* 13, 1095–1097. doi: 10.1016/j.molp.2020.07.01

Naqvi RZ, Siddiqui HA, Mahmood MA, Najeebullah S, Ehsan A, Azhar M, Farooq M, Amin I, Asad S, Mukhtar Z, Mansoor S and Asif M (2022) Smart breeding approaches in post-genomics era for developing climate-resilient food crops. *Front. Plant Sci.* 13:972164. doi: 10.3389/fpls.2022.972164

Potts, Jesse, Sumit Jangra, Vincent N. Michael, and Xingbo Wu. (2023).Speed Breeding for Crop Improvement and Food Security" *Crops* 3, no. 4: 276-291. https://doi.org/10.3390/crops3040025