Breeding for Sustainable Agriculture and Food Security

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The interesting topic of sustainable agriculture and food security is explored in this book chapter. It looks at the difficulties in feeding the world's expanding population, highlighting how plant breeding may increase food yields and resilience. The chapter examines the use of genetically modified organisms (GMOs), the creation of crops resistant to abiotic stress, and techniques for water-saving farming. Additionally, it talks about how important plant growth-promoting rhizobacteria (PGPR) are to crop productivity and soil health. The chapter discusses the Green Revolution's historical relevance as well as its effects on the security of food and nutrition. The significance of genetics and sophisticated breeding techniques for crop types robust to climate change is emphasized.

Keywords: *Food security, Green revolution, Crop productivity, Climate change*

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Introduction

Approximately 800 million people worldwide endure chronic hunger, and up to 2 billion people are undernourished in vital micronutrients (FAO 2019a). Crop yields have increased dramatically as a result of plant breeding, especially in the last century (Pray et al., 2018). Global food systems must undergo significant changes if these issues are to be resolved and Sustainable Development Goal 2—"zero hunger and improved nutrition" to be achieved. Complex problems cannot be solved by isolated solutions (Meemken and Qaim, 2018; Springmann et al., 2018; FAO 2019a). Production of huge amount of food for the increasing population has always challenging since agriculture has been started around 12,000 years ago. With increasing agricultural production increase of agrochemicals with unsustainable agricultural practices has negative impact on the environment. Climate change with increasing temperature, drought and other abiotic and biotic stress gives poor yield. Most of the poor families in Africa and Asia depend on agriculture, due to climate change they will suffer more which will affect their income and livelihood (Wheeler and von Braun, 2013). The second half of the nineteenth century saw the start of a new phase in the struggle between food supply and population increase. Research on agriculture grew increasingly scientific. fresh knowledge on the nutrition, genetics and technological developments in the chemical industry expedited the agricultural innovation to a large extent. The creation and dissemination of enhanced crop variety, the application of synthetic fertilizers, and other contemporary inputs resulted in significant gains in agricultural production in Europe and the USA during the initial part of the 20th century (Qaim, 2016).

Principles of sustainable agriculture

In addition to being directly impacted by climate change, intensive conventional agriculture also adds to biodiversity loss, water pollution, and the depletion of natural resources. Although there is widespread recognition of these concerns, we still maintain excessive and unsustainable consumption and production patterns that are driving us beyond the limits of our planet or toward irreversible tipping points. Therefore, if food production keeps up its current pace, the world as we know it is doomed (United Nations, 2019).

The primary principle, integrated management, accepting plant protection and natural pest management as the class's stronger ideas, we believe that sustainable agriculture ought to be founded on agro-ecology principles when an integrated and regenerative strategy is required and should thus be enforced. Solutions based on nature, are economical solutions that draw inspiration and support from the natural world. They naturally promote resilience while offering advantages to the environment, society, and economy. It is widely accepted that these approaches enhance biodiversity and facilitate the provision of a variety of ecosystem facilities (European Commission, 2020).

The term "natural capital valorization" refers to the idea that in order to attain sustainability, natural and human capital must be combined. Because human knowledge and ecosystem services should be taken into account when making decisions within our production system, farmers need to be aware of the best alternative agricultural techniques for their particular circumstance and context at a given time and location. Understanding the entire system is therefore necessary to produce effectively and sustainably and to determine the circumstances in which agricultural inputs either support or contradict biological processes (Pretty et al., 2014; Settle et al., 2014).

Secondary principle includes real time balance management. Ecological and economic indicators constituted the majority of the major lexicon, which revolved around off-farm inputs and their direct effects on natural resources like soil and water, or farm outputs and their influence on our income and productivity. To be able to adapt and maximize, we must constantly review and evaluate in order to find equilibrium in each given circumstance. The ability to adjust to unforeseen developments and new uncertainties is what sustainability is, not the fossilization of anything (Pretty et al., 2014). The long-term equilibrium of the global economy and ecosystem is the ultimate aim, and this concept suggests that it is more attainable during the cycle of continual assessment, adaptation, and assessment. Thus, the two main terms of this principle are continuity and balance.

Role of plant breeding technology in agriculture

It justifies the different scientific methods and processes for the creation of new plant varieties with desired traits. Plant breeding techniques include the crossing of two different species to create a new progeny with desirable traits. The three-step procedure includes collecting germplasm, selection of best phenotype among all and better performing cultivars which are the result of hybridisation (Al-Khayri et al., 2016). After several years of stabilization, a selection of plants is made from the diverse population. The improved features of the resultant plants are tested in a variety of environments. Rajaram revealed in 1996 that he used 51 crops gathered from 21 different nations to cross wheat 3170 times (Rajaram et al., 1996).

Furthermore, because plant breeding technology combines both contemporary molecular techniques like genetic engineering and gene editing with more established breeding procedures like hybridization and cross-pollination, it is a great aid to agriculture. By using these methods, scientists are able to transfer desired genes from one plant to another, giving rise to plants with superior characteristics. Due to its ability to aid in the development of new crop types with higher yield potential, it is well known for its increased crop production. Consequently, this raises the agricultural system's total production, which is necessary to meet the world's expanding food demand (Unkovich et al., 2023). Using the latest plant breeding techniques could result in a more sustainable agriculture system by lowering the usage of chemical pesticides and other hazardous substances. Additionally, with the use of this technology, crops that are resistant to environmental challenges like heat, salinity, and drought can be developed. In regions where food security is at risk from climate change, this is crucial. Using this method, scientists can preserve the genetic diversity of crops, guaranteeing that valuable features are retained and can be applied to new breeding initiatives.

Table 1. This table highlights the major biotic and abiotic stresses impacting key crops around the world. Each stress factor poses significant challenges to global agriculture, affecting crop productivity and food security.

Crop	**Biotic Stresses**	**Abiotic Stresses**
Wheat	- Rust (*Puccinia spp*.)	- Drought
	- Fusarium Head Blight (*Fusarium* spp.)	- Heat stress
	- Aphids (*Aphididae*)	- Cold stress
	- Nematodes (*Heterodera spp*.)	- Salinity
	- Powdery Mildew (*Blumeria graminis*)	- Waterlogging
Rice	- Rice Blast (*Magnaporthe oryzae*)	- Drought
	- Bacterial Blight (*Xanthomonas oryzae*)	- Salinity
	- Brown Planthopper (*Nilaparvata lugens)*	- Heat stress
	- Rice Yellow Mottle Virus	- Flooding
Maize (Corn)	- Maize Lethal Necrosis	- Drought
	- Fall Armyworm (*Spodoptera frugiperda)*	- Heat stress
	- Maize Streak Virus	- Cold stress
	- Northern Corn Leaf Blight (*Exserohilum turcicum*)	- Nutrient deficiency
Soybean	- Soybean Cyst Nematode (*Heterodera glycines*)	- Drought
	- Asian Soybean Rust (*Phakopsora pachyrhizi*)	- Salinity
	- Bean Pod Mottle Virus	- Heat stress
	- White Mold (*Sclerotinia sclerotiorum*)	- Flooding
Cotton	- Boll Weevil (*Anthonomus grandis*)	- Drought
	- Cotton Leaf Curl Virus	- Salinity
	- Fusarium Wilt (*Fusarium oxysporum*)	- Heat stress
	- Root-Knot Nematodes (*Meloidogyne spp.*)	- Cold stress
Potato	- Late Blight (*Phytophthora infestans*)	- Drought
	- Potato Cyst Nematode (*Globodera spp*.)	- Heat stress
	- Bacterial Wilt (*Ralstonia solanacearum*)	- Frost
Tomato	- Colorado Potato Beetle (*Leptinotarsa decemlineata*)	- Waterlogging
	- Tomato Yellow Leaf Curl Virus	- Drought
	- Late Blight (*Phytophthora infestans*)	- Salinity
	- Fusarium Wilt (*Fusarium oxysporum*)	- Heat stress
	- Tomato Hornworm (*Manduca quinquemaculata*)	- Nutrient deficiency

Banana	- Panama Disease (*Fusarium oxysporum f.sp. cubense*)	- Drought
	- Black Sigatoka (*Mycosphaerella fijiensis*)	- Salinity
	- Banana Bunchy Top Virus (BBTV)	- Wind damage
	- Nematodes (*Radopholus similis*)	- Temperature extremes

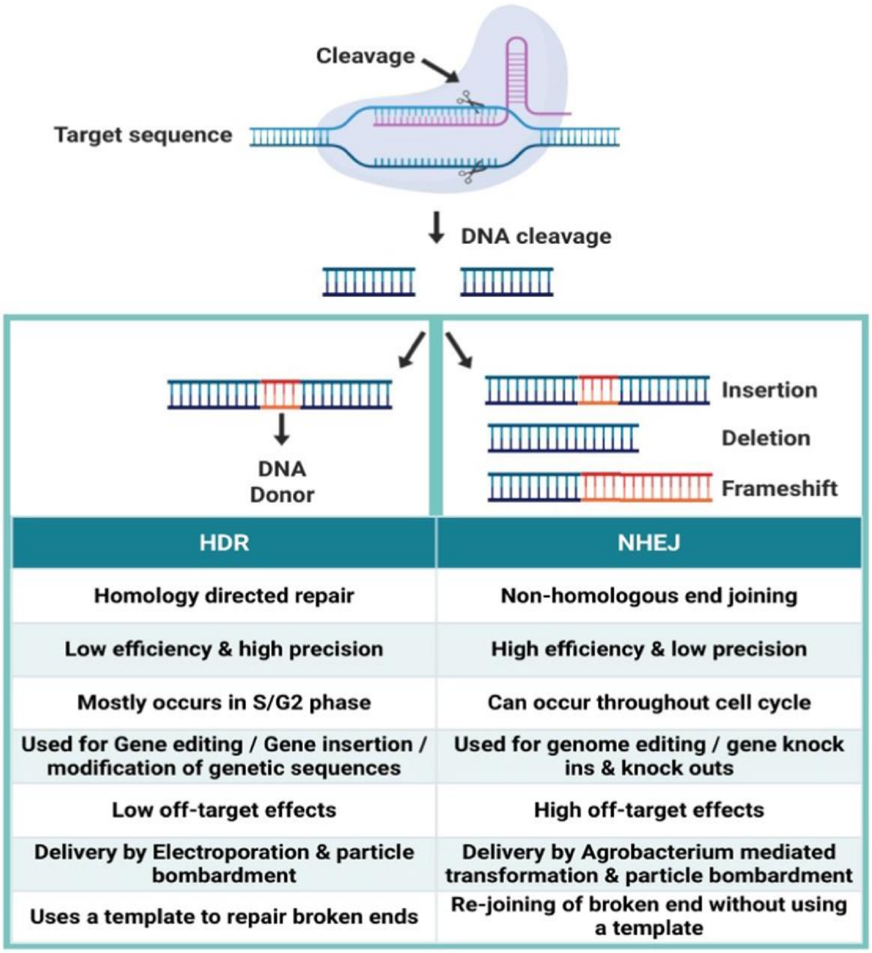
Effect of abiotic stress on crop

Stress in agriculture is considered as negative for the growth and production of crops. Abiotic stress includes some environmental factors such as drought, light, temperature, properties of soil, etc. Stresses from the environment have an impact on crop physiology, growth, development, yield, and quality. Understanding the interactions between environmental elements and physiological processes is crucial for improving agricultural methods (Rao et al., 2016). Crops experience morphological and molecular effects from stress. Every underlying process is considered in the responses at the entire crop level. This means that it's not always easy to evaluate these investigations quantitatively. Furthermore, this issue will get worse due to climate change (Calanca, 2017).

Abiotic stress can cause changes in a plant's water relations, water consumption efficiency, photosynthetic capacity, gas exchange, food acquisition, protein synthesis, and formation and accumulation of organic solutes (Talaat, 2019). Light is one of the most crucial environmental elements for the growth and development of plants. It controls not only the development and production of plants but also the rate of photosynthetic oxidation and accumulation-assimilation. However, excessive or insufficient light exposure, known as light stress, can negatively impact a plant's agronomic features by impeding physiological metabolic activities like photosynthesis, antioxidant production, and nitrogen and carbon fixation (Yang et al.,2019). Symbiotic connections and soil microbial biodiversity among soil microorganisms, which support physiological processes and plant nutrient intake, have a direct impact on biomass output. Abiotic stressors such as drought, excessive salinity, and other abiotic stressors have been shown to have either a positive or negative impact on plant carbon metabolism, contingent upon the stress rate, plant species, and plant tissue type (Abdul Rahman et al., 2021).

Abiotic resistant crop development with the help of breeding technology

It refers to different approaches and procedures to enhance the genetic composition of plants in order to achieve desired characteristics including quality, tolerance, yield, and disease resistance. The goal of plant breeding is to create new cultivars that can better suit particular conditions and satisfy the demands of farmers, consumers, and the food industry. Various breeding technologies are employed to enhance the ability of crops to withstand abiotic stress. One method is to find and choose plants that have desirable characteristics like heat, salt, and drought resistance using conventional breeding techniques. Subsequent generations may inherit these features and generate new kinds with enhanced stress tolerance. Using this technique for millennia has led to the development of numerous crop kinds that are still commonly farmed today (Palareti et al., 2016). For instance, durum wheat is susceptible to salinity because of the absence of the *HKT1;5* gene, which blocks Na^+ from the xylem root. Given that this allele is both species can be crossed when they are present in bread wheat in order to transfer the *HKT1;5* genomic variant to durum wheat. Grain yield under salinity stress was discovered to be 25% more in the *HKT1;5* containing durum lines (Munns et al., 2012). Utilizing genetic engineering technology to give plants particular genes that increase their resistance to abiotic stress is an additional strategy. To increase a crop's resistance to salt and drought, for instance, genes encoding the enzymes needed for the manufacture of osmoprotectants including proline, glycine betaine, and trehalose have been inserted into the plant. Likewise, heat-shock protein and antioxidant genes have been inserted into crops to aid improve their resistance to high temperatures (Rani et al., 2021; Roy et al., 2011). With the help of recent developments in genome editing technologies like CRISPR/Cas9, plant genomes may now be precisely and specifically modified, speeding up the process of breeding crops with desired characteristics. It is possible to add or change the genes that provide resistance to abiotic stress by genome editing (Jinek et al., 2012).



HDR	NHEJ
Homology directed repair	Non-homologous end joining
Low efficiency & high precision	High efficiency & low precision
Mostly occurs in S/G2 phase	Can occur throughout cell cycle
Used for Gene editing / Gene insertion / modification of genetic sequences	Used for genome editing / gene knock ins & knock outs
Low off-target effects	High off-target effects
Delivery by Electroporation & particle bombardment	Delivery by Agrobacterium mediated transformation & particle bombardment
Uses a template to repair broken ends	Re-joining of broken end without using a template

Figure 1. CRISPR/Cas9 genome editing

Breeding for nutritional security with genomics

There is a big history of using conventional plant breeding techniques to increase crop yield, productivity, food safety, and nutritional security (Kaiser et al., 2020). Numerous nutrient-dense crop types of various food crops have been made available for global planting. Many bio-fortified crops, such as iron-rich beans, iron-rich pearl millet, vitamin A-rich maize, zinc-rich rice, and zinc-rich wheat, have been developed by Harvest Plus in cooperation with various partners worldwide. These crops have been approved for cultivation in more than 30 countries (https://www.harvestplus.org/what-we-do/crops). It is imperative to address any food safety issues pertaining to allergenicity and toxicity of crop products before they are consumed by consumers, in addition to enhancing nutrition security. A variety of crops, including wheat, soybean, peanut, and others, have undergone conventional breeding methods and genomics assisted breeding (GAB) efforts toward hypoallergenic varieties because it is laborious to screen crop germplasm for genotypes with significantly reduced or null allergen content (Kaiser et al., 2020).

Some of the genomic based tools and techniques for improvement in agriculture are:

- Molecular markers
- Genome Sequencing
- Quantitative trait locus (QTL)
- Genome-wide association mapping

In peanut some of allergens are there which are having harmful effects for some of the allergic people. To tackle this problem hypoallergenic peanuts can be used. The thorough study by Pandey, Varshney, and colleagues described an antibody-based ELISA procedure for accurately measuring and standardizing the five main allergen proteins in peanut seeds (Ara h 1, Ara h 2, Ara h 3, Ara h 6, and Ara h 8). By using this approach, it will be possible to select genotypes with the lowest level of allergenicity from peanut germplasm on a wide scale, ensuring the safety of food. One of the most significant fields of agricultural research is the mapping of genes/QTLs for quantitative traits using QTL mapping, association mapping, and genome-wide association studies (GWAS). Sab et al., 2020, found the concentration of Zn and Fe in seeds using genes and QTLs. There were eight (8) QTLs found for seed Zn concentration and eleven QTLs found for seed Fe concentration. Of the QTLs that were found, three of them were found to be co-located in the "QTL-hotspot" region on linkage group-04, which is also home to a few QTLs associated with drought tolerance that have been found and documented in previous research (Pandey et al., 2019). The information gathered from this study may prove useful in the creation of chickpea bio-fortified varieties using genomics assisted breeding (GAB) techniques.

Obstacles posed by laws and regulations to the creation and marketing of new varieties

The impact of genetically modified (GE) crops on consumers and the environment worries people. For example, gene transfer to non-target proteins raises health and environmental issues. The plants are injected with markers that are resistant to antibiotics, enabling the selection of plant cells that have undergone successful gene transfers. Genes that confer antibiotic resistance may be incorporated into the gut of a consumer (human, insect, or animal) through genetic engineering (GE) crops. Regarding the emergence of resistance in pests and insects that consume BT cotton, farmers have expressed grave worries (Wolter *et al.*, 2019). Strict laws have been implemented in several nations to address the problems associated with the production and sale of genetically modified organisms (GMOs).

Globally, the GMO regulation system is based on two primary approaches:

(i) Product-based regulation of genetically modified plants, in which the emphasis is on the finished good rather than the manufacturing method. This approach maintains the belief that there is no health risk associated with the producing method. Therefore, the risk is limited to the finished product and is not affected by the genetic engineering technology employed. This system is used by the US, Chile, Australia, Russia, Argentina, and other countries because it is dependable, easy to use, and compliant with free trade agreements with the World Trade Organization (WTO). Additionally, this lessens the limitations on the control of GE crops (Ahmad et al., 2021). (ii) Process-based GM plant regulation, in which the method distinguishes between non-GM and GM crops. This method operates under the premise that possible dangers are also influenced by the process used to produce genetically engineered crops. This makes the assumption that genes do not naturally move between species, and any divergence suggests that genetic engineering has been used to produce the crop. GMOs are regulated in the European Union (EU) by this system, which makes use of EU directive 2001-18-EC (2001) and EC regulation 258-97 (1997) (Zhang et al., 2018a, b).

Planning for the future sustainability

The first simple approach to creating crops that will satisfy the demands of sustainable agriculture in the future is to enhance the following features of already farmed crops.

Improving yield

According to estimates, in order to meet the demand for food by 2050, major crop yields will need to increase at a rate of 2.4% per year. But the four main crops which are, soybeans (*Glycine max*), wheat (*Triticum aestivum*), rice (*Oryza sativa*), and maize (*Zea mays*)—are currently growing at only about half the predicted rate (Ray et al., 2013). The primary goal of the Future Crops Design project is to create new, high-yielding varieties that can bridge this gap. In fact, according to an experiment, a super-high-yield rice variety might produce one to three times as many grains under ideal circumstances as it did in typical paddy fields (Liu et al., 2020a).

Nutrition quality

A phenomenon known as hidden hunger has emerged despite substantial improvements in the food supply over the past 50 years due to changes in human consumption patterns and lifestyle (Nair et al., 2016). For example, between 17% and 30% of children under the age of five in sub-Saharan Africa and America do not get enough Vitamin A each day (Harjes et al., 2008, Haskell, 2012). Therefore, the second goal of the Future Crops Design project is to use synthetic biology and metabolic engineering to create crops with specialized metabolites or higher/balanced nutritional quality (Francis et al., 2017, Martin and Li, 2017, Sweet love et al., 2017, Vasconcelos et al., 2017).

Rhizobacteria for sustainable development

Agriculture's sustainability depends on the soil's ability to remain dynamic (Paustian et al., 2016). In India, half the population cultivates a variety of crops, including pulses, vegetables, and cereals, on 60.6% of the country's land.

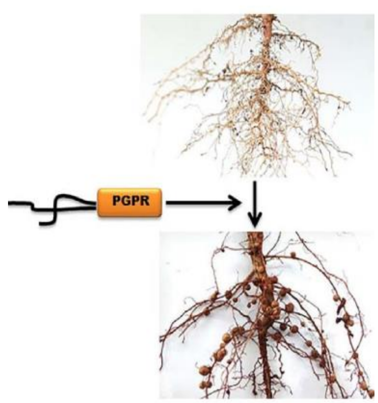


Figure 2. PGPR (Plant Growth Promoting Rhizobacteria) (Gouda et al., 2018)

The interplay of nutrients, energy, and carbon among soil organic matter, the aquatic ecosystem, the soil environment, and the atmosphere has a substantial impact on the quality of water, agricultural productivity, and the consequences of climate change *(*Lehmann and Kleber, 2015). The microorganisms known as PGPRs, or Plant Growth-Promoting Rhizobacteria, play a major role in the conversion of unproductive, poor-quality land into arable soil. Research on using PGPR to promote plant growth and revitalize soil quality has been conducted in a number of different parts of the world (Gabriela et al., 2015).

Conclusion

One of the most important tools for tackling the related problems of food security and sustainability is plant breeding. We can boost crop resilience, raise yields, and raise the nutritional value of our food sources by using creative breeding strategies. This lessens the negative effects of agriculture on the environment while also assisting in ensuring a consistent and dependable supply of food. Adopting sustainable plant breeding techniques not only helps the current generation but also builds the groundwork for a more stable and prosperous future in which food can be plentiful and nourishing while reducing the demand on the resources of our planet. Plant breeding plays a critical role in promoting food sustainability and security as the world's food concerns continue to evolve.

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