Journal of Agricultural Research Advances
ISSN: 2582-7227

Review Article
Open Access

Rice breeding and genetics: The impact of climatic change and pestilence on global rice production

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Received on: 25/04/2025 Accepted on: 27/08/2025 Published on: 01/09/2025

ABSTRACT

Rice (*Oryza sativa* L.) is one of the most crucial staple crops globally, providing sustenance to over half of the world's population. However, rice production faces significant challenges due to climate change and the rising prevalence of pests and diseases, which are threatening food security worldwide. Climate change, characterized by increasing temperatures, erratic rainfall patterns, and extreme weather events, has a direct impact on rice cultivation by disrupting plant growth, flowering, and grain formation, leading to reduced yields. Similarly, pestilence exacerbated by altered climatic conditions, fosters the spread of the brown plant-hopper (*Nilaparvatalugens*) and diseases like rice blast (*Magnaporthe oryzae*), further damaging crops. To mitigate these challenges, modern rice breeding techniques, including genetic modification and genome editing, have been pivotal in developing climate-resilient and pest-resistant rice varieties. Bio-fortification efforts, such as Golden Rice (enriched with Vitamin A), have been developed to address micronutrient deficiencies in rice-consuming populations too.Therefore this study was setup to examine the interplay between climate change, pestilence, and rice productivity, focusing on the genetic advancements aimed at improving rice's pestilence. By exploring the effectiveness of biotechnological innovations in addressing these global threats, this study highlights the potential of genetically improved rice varieties to ensure future food security in a changing climate.

Keywords: Rice blast; Pests/Disease resistant varieties; Gene editing; Climate change; Rice

How to cite this article: Etaware PM, Jacob OL, Egara OW and Ekun VS (2025). Rice breeding and genetics: The impact of climatic change and pestilence on global rice production. J. Agri. Res. Adv., 07(03): 07-14.

Introduction

Rice (*Oryza sativa* L.) is a staple food crop virtually sustaining more than three (3) billion people on daily basis, making it an essential component for the fight against hunger and starvation,inadvertently ensuring global food security (FAO, 2021). As a major source of energy, proteins, and essential nutrients, rice plays a crucial role in food security, particularly in Asia, Africa, and Latin America (Zhang *et al*., 2019). Globally, rice is cultivated on approximately 162 million hectares, making it the second most cultivated cereal crop after maize (IRRI, 2022). However, climate change and pestilence have significantly threatened rice production in recent years.

Climate change has led to unpredictable weather conditions such as rising temperatures, changes in rainfall patterns, and extreme weather events, all of which affect rice yields (Li *et al*., 2020). High temperatures can disrupt rice flowering and grain formation, leading to lower productivity (Jagadish *et al*., 2021). Similarly, excessive rainfall and flooding can damage crops, while droughts limit water availability for irrigation (Wassmann *et al*., 2019). Another major challenge is pestilence, which refers to the increasing prevalence of pests and diseases affecting rice crops (Sharma *et al*., 2020). The rise in temperature and humidity has created favorable conditions for pests such as the brown planthopper (Nilaparvatalugens) and diseases like rice blast (Magnaporthe oryzae), leading to severe crop losses (Savary *et al*., 2019). As a result, rice breeders and geneticists have focused on developing climate-resilient rice varieties through genetic modifications and biotechnological interventions (Xu *et al*., 2022). However, climate variability and the increasing occurrence of pestilence pose a severe threat to its production (Zhang *et al*., 2019). Without appropriate interventions, global rice yields could decline significantly by 2050, exacerbating hunger and malnutrition (Jagadish *et al*., 2021). Irrespective of the concerted effort put in place to improve the nutrient quality of rice such as bio-fortification of golden rice brand (i.e., enriched with Vitamin A), which was developed to address micronutrient deficiencies in rice-consuming populations (Dubock, 2019), the problem of malnutrition, pestilence and inadequacy of rice supplied within the global market persist.This research therefore aims to examine the effects of climate change and pestilence on rice production and to evaluate the effectiveness of genetic breeding in developing resistant rice varieties. The current study seeks to analyze the impact of rising temperatures, changing rainfall patterns, and extreme weather events on rice cultivation (Li *et al*., 2020). Investigate the major pests and diseases affecting rice productivity and their correlation with climate change (Sharma *et al*., 2020). Assess the role of modern rice breeding techniques, including genetic modification and genome editing, in mitigating climate and pest-related risks (Xu *et al*., 2022). Evaluate global efforts in promoting sustainable rice farming practices and disease management strategies (Savary *et al*., 2019). By addressing these objectives, this study will contribute valuable insights into sustainable rice production amid changing environmental conditions. Recent advancements in rice genetics have shown promise in developing stress-tolerant varieties (Xu *et al*., 2022). Through genetic engineering, researchers have enhanced drought tolerance, pest resistance, and heat resilience in rice (Wassmann *et al*., 2019). Understanding the effectiveness of these interventions is crucial for ensuring the sustainability of rice production in the face of climate change and pestilence (Li *et al*., 2020). Therefore, this research is timely and relevant, as it seeks to address critical challenges that threaten global food security while exploring scientific advancements in rice breeding.

Descriptions, Taxonomy, and Composition of Rice

Botanical Descriptions of Rice:

Rice (*Oryza sativa* L.) is a monocotyledonous cereal plant from the Poaceae family, which includes other grains such as wheat and maize (IRRI, 2022). It is an annual grass that typically grows between 60 cm and 1.5 meters tall, depending on the variety (Wang *et al*., 2020).The rice plant consists of roots, culms (stems), leaves, panicles (flowering heads), and grains (Wassmann *et al*., 2019). The roots provide anchorage and water absorption, while the hollow culm supports the plant structure. The leaves, long and narrow, facilitate photosynthesis, and the panicle holds the rice grains, which are the plant's reproductive structures (Sharma *et al*., 2020). Rice has three major growth stages: the vegetative stage (seedling establishment), the reproductive stage (flowering), and the ripening stage (grain maturity) (Xu *et al*., 2022). Optimal conditions for growth include temperatures between 20°C-35°C, a well-irrigated environment, and fertile, well-drained soil (Jagadish *et al*., 2021).

Taxonomy of Rice:

Rice belongs to the family "*Poaceae*". The general taxonomy of rice is as follows:

Kingdom: Plantae
Division: Angiosperms
Class: Monocots
Order: Poales
Family: Poaceae
Genus: Oryza
Species: *Oryza sativa* L. (Asian rice), *Oryza glaberrima* (African rice)

Rice is further classified into subspecies and cultivars based on grain type, growth duration, and environmental adaptability. The two primary subspecies of *Oryza sativa* L. are:

1. *Oryza sativa* Subsp. *indica*: Long-grain, non-sticky rice commonly grown in tropical and subtropical regions.
2. *Oryza sativa* Subsp. *japonica*: Short-grain, sticky rice cultivated in temperate regions such as Japan and Korea.

The wild relatives of cultivated rice, including *Oryza rufipogon* and *Oryza nivara*, contribute valuable genetic traits for breeding programs aimed at improving stress tolerance and disease resistance (Wing *et al*., 2018).

Proximate Composition of Rice

According to Kumar *et al*. (2022), the proximate composition of milled rice consist basically of carbohydrate (≤80%), protein (≤10%), lipids (≤3%), and dietary fibre (≤2%), as shown (Table 1). It was noted that the major component of the carbohydrate found in rice was basically starch, a complex polysaccharide, whereas glutelin and protamine were the most abound primary component of rice protein (Table 2). The average moisture content per milled sample of rice was measured to be within the range 12%≤moisture content of rice≤15%, this was shown (Table 1). Brown rice contains more fiber, vitamins, and minerals than white rice due to the retention of the bran layer (Sharma *et al*., 2021).

Table 1. Proximate analysis of rice

Component	Content	Source/Composition
Carbohydrates:	75–80%	Mainly starch
Proteins:	6–10%	Glutelin and protamine
Lipids:	0.5–3%	Mainly found in bran
Dietary fiber:	0.2–2%	Higher in whole grain rice
Moisture content:	12–15%	Water

Phytochemical Composition of Rice

Rice contains various bioactive compounds with antioxidant, anti-inflammatory, and anti-diabetic properties. Notable phytochemicals include:

- Phenolic compounds: Ferulic acid, p-coumaric acid, and flavonoids.
- Tocopherols and Tocotrienols: Present in rice bran oil, beneficial for heart health.
- Gamma (γ) -oryzanol: A potent antioxidant found in rice bran (Chouhan *et al*., 2020).

Mineral Composition of Rice

The mineral content of rice varies depending on the soil and cultivation practices. It was noted that the most abundant mineral element found in rice was magnesium, which was calculated to measure about 60 mg/100g of milled rice (Wang *et al*., 2019). Other mineral elements present were Iron (≤3.5 mg/100g of milled rice), zinc (≤2,8 mg/100g of milled rice), while the least abundant mineral element detected in the milled rice sample was selenium (≤30 µg/kg of milled rice), as shown (Table 2).

Table 2. Mineral composition of rice

S/N	Mineral Element	Composition(mg/100g)
1.	Iron (Fe)	0.2–3.6
2.	Zinc (Zn)	1.0–2.8
3.	Magnesium (Mg)	20–60
4.	Selenium (Se)	5–30 (µg/kg)

Major Pests and Diseases of Rice

Rice is vulnerable to various pests and diseases that significantly reduce yield and quality. Climate change exacerbates these issues by altering pathogen and pest dynamics (Savary *et al*., 2019).

Major Rice Diseases

Climate factors like increased temperature and humidity promote disease outbreaks by creating favorable conditions for pathogen growth (El-Nashar *et al*., 2022). Some important diseases of rice were stated below:

- Rice blast (*Magnaporthe oryzae*) – A fungal disease causing lesions on leaves, stems, and panicles, leading to significant yield loss.
- Bacterial blight (*Xanthomonas oryzae* pv. *oryzae*) – A bacterial infection resulting in yellowing and wilting of leaves.
- Sheath blight (*Rhizoctoniasolani*) – A fungal disease that affects the lower leaves, reducing grain filling and yield.
- Rice tungro virus – A viral disease transmitted by leafhoppers, causing stunted growth and reduced productivity.

Major Rice Pests

Changing climate conditions, such as erratic rainfall and rising temperatures, contribute to pest outbreaks by altering pest life cycles and increasing their survival rates (Gagné *et al*., 2020). Some important pests of rice include:

- Brown plant-hopper (*Nilaparvatalugens*) – A major insect pest that causes hopper burn and transmits rice viruses.
- Stem borers (*Scirpophagaincertulas*) – Larvae that tunnel into rice stems, leading to dead hearts and whiteheads.
- Rice weevils (*Sitophilus oryzae*) – Post-harvest pests that infest stored rice grains.

General Pest and Disease Management of Rice

Effective pest and disease management strategies are critical to sustaining rice production. These approaches include:

1. Cultural Practices

- Crop rotation – Reduces pathogen and pest buildup by alternating rice with non-host crops.
- Resistant varieties – Breeding disease-resistant rice varieties, such as IR64 and Swarna-Sub1, enhances resilience against pathogens (Singh *et al*., 2021).
- Field sanitation – Removal of infected plant debris minimizes disease recurrence.

2. *Biological Control*
- Use of beneficial microbes – Trichoderma spp. suppress fungal pathogens like Magnaporthe oryzae.
- Natural predators – Spiders and parasitoid wasps control rice insect pests.

3. *Chemical Control*
- Fungicides – Propiconazole and carbendazim are used against rice blast.
- Insecticides – Neonicotinoids help manage brown planthoppers.
- Seed treatments – Systemic pesticides protect seedlings from early infestations (Yasuda *et al*., 2022).

Integrated Pest Management (IPM)

Integrated pest management (IPM) combines multiple strategies, including resistant varieties, biological agents, and judicious pesticide use, to minimize pest damage while reducing environmental impact (Islam *et al*., 2023).

Advances in Rice Cultivation and Breeding

Traditional Cultivation of Rice

Rice is one of the oldest cultivated crops in the world, and traditional cultivation methods remain prevalent in many parts of Asia, Africa, and South America. These methods, while labor-intensive, rely heavily on local ecological knowledge and are adapted to specific regional conditions. They form the backbone of rice production in developing countries, where mechanization and modern agricultural practices may be less accessible (Hossain*et al*., 2020).

Rainfed Lowland Rice Cultivation:

This system is characterized by fields that are flooded naturally during the monsoon season. Farmers cultivate rice in paddy fields, which are submerged with water for the majority of the growing season. Rainfed lowland rice cultivation is particularly common in Southeast Asia, India, and parts of Africa (Mondal*et al*., 2017).

Characteristics of Rain-fed Lowland Cultivation:
- This system of traditional cultivation of rice is solely dependent on seasonal rainfall patterns, making it vulnerable to climate change-induced variations in precipitation (Ali *et al*., 2018).
- Traditional methods for rice cultivation can suffer from poor water management, leading to stagnation or drying of the fields (Singh and Singh, 2019).
- Low productivity due to soil degradation, lack of proper irrigation systems, and pest pressures (Hussain *et al*., 2018).

While this system requires minimal input, its low productivity and vulnerability to flooding or drought due to climate variability make it less reliable, thus challenging food security in some regions (Tan *et al*., 2020).

Upland Rice Cultivation

Upland rice cultivation takes place in non-flooded areas, often on sloped fields or hillsides. This method is common in regions where water availability is limited or where the terrain prevents the establishment of traditional paddy fields. Upland rice farming often relies on organic matter such as crop residues for soil fertility (Miah *et al*., 2019).

Characteristics of Upland Cultivation:
- Less water-intensive than other systems, making it more suitable for drought-prone areas (Khush, 2020).
- Can be highly sustainable if traditional soil conservation techniques, such as terracing, are applied (Bertin *et al*., 2021).
- Yields tend to be lower than in irrigated systems due to poorer soil fertility and high weed competition (Khan *et al*., 2017).

Despite being more resistant to drought, upland rice faces challenges such as poor soil quality, erosion, and weed infestations (Singh *et al*., 2018). Farmers also struggle with access to high-quality seed varieties and fertilizers, limiting the potential for yield improvements (Yin *et al*., 2017).

Irrigated Rice Cultivation

Irrigated rice farming involves fields that are artificially flooded using irrigation systems, such as canals, wells, or pumps. This system is widespread in areas where water is available year-round and is a dominant form of rice cultivation in countries like China, India, and the United States (Liu *et al*., 2019).

Characteristics of Irrigated Rice Cultivation:
- Allows farmers to grow rice throughout the year, increasing productivity and efficiency (Zhang *et al*., 2021).
- Provides control over water availability, enabling better management of water resources (Sharma *et al*., 2018).
- Requires significant infrastructure and investment in irrigation systems (Papanicolaou and Yoder, 2019).

Although highly productive, irrigated systems are water-intensive and have a higher carbon footprint due to the energy required for irrigation (Khan *et al*., 2020). Moreover, overuse of irrigation in some regions can lead to salinization of the soil and depletion of water resources (Hussain *et al*., 2020).

Deepwater Rice Cultivation

Deep water rice is typically grown in regions prone to flooding, such as in parts of Southeast Asia. Such variety and type of rice is adapted to survive in flooded conditions by elongating its stem to emerge above water's surface (Boserup, 2021).

Characteristics of Deepwater Rice Cultivation:

- Can withstand submergence and is cultivated in flood-prone areas (Singh *et al*., 2020).
- The varieties used are often long-stemmed and can grow in water depths ranging from 50 cm to 1 meter (Rahman *et al*., 2019).
- Low productivity compared to other systems due to the unstable growing environment (Rahman and Siddique, 2021).

Deepwater rice faces low yields and challenges with soil fertility and nutrient availability, and its cultivation is highly dependent on the timing and intensity of flooding (Ghosh and Bhattacharya, 2020).

Modern Breeding Techniques for Rice Production

In contrast to traditional methods, modern rice breeding techniques leverage scientific knowledge, technologies, and innovation to enhance rice production, making it more efficient, resistant to environmental stress, and suited to modern farming conditions (Virk *et al*., 2020). Some of the key techniques used today include:

Conventional Breeding: Conventional breeding remains the foundation of many modern rice breeding programs. By selecting rice plants with desirable traits, such as high yield, disease resistance, and good grain quality, researchers have developed high-performing rice varieties that can thrive under a variety of conditions (Borlaug *et al*., 2020).

Advantages:

- Long-standing, reliable methods with proven results (Borlaug, 2019).
- Can be done without sophisticated technology (Sharma *et al*., 2017).
- Effective for improving traditional traits such as grain size, quality, and resilience (Kumar *et al*., 2018).

Disadvantages:

- Time-consuming and requires several generations to stabilize desired traits (Khan and Siddiqui, 2021).
- Limited by genetic diversity and the natural variation available (Ali *et al*., 2019).

Hybrid Rice Breeding

Hybrid rice involves crossbreeding of two genetically distinct rice varieties to exploit hybrid vigor which results in higher yields and better overall performance. Hybrid rice has been widely adopted in China and several other countries, increasing yield by 15-30% (Yuan, 2019).

Advantages:

- Significant yield increases compared to conventional inbred varieties (Fujita *et al*., 2019).
- Hybrid vigor leads to improved pest resistance, disease resistance, and overall growth (Huang *et al*., 2018).

Disadvantages:

- Requires farmers to buy new seeds each year as hybrids cannot be saved for the next planting season (Zhang and He, 2020).
- High seed costs and challenges with seed production (Guo *et al*., 2020).

Marker-Assisted Selection (MAS)

Marker-assisted selection utilizes molecular markers to identify genetic traits linked to desirable characteristics such as disease resistance, drought tolerance, and pest resistance. By using genetic markers to select the best plants early in their growth cycle, MAS accelerates breeding process (Jiang *et al*., 2021).

Advantages:

- Increases the precision and speed of traditional breeding techniques (Kumar *et al*., 2020).
- Allows for the selection of beneficial traits without waiting for full plant maturation (Fukui *et al*., 2019).

Disadvantages:

- Requires access to molecular biology labs and expertise (Virk *et al*., 2020).
- Relatively expensive compared to traditional breeding methods (Ali and Ismail, 2020).

Genome Editing (CRISPR-Cas9)

Genome editing technologies, particularly CRISPR-Cas9, allow for the precise modification of specific genes in rice. This can lead to the creation of rice varieties with enhanced resistance to diseases, pests, and environmental stresses, or improved nutritional profiles (Zhang *et al*., 2021).

Advantages:

- Highly precise, targeting specific genes for modification (Virk *et al*., 2020).
- Faster than traditional breeding, with fewer unintended genetic changes (Gao *et al*., 2021).
- Offers potential for improving rice's nutritional value, such as enhancing vitamin content (Jiang *et al*., 2020).

Disadvantages:

- Faces significant regulatory hurdles and acceptance challenges in some regions (Borlaug, 2021).
- Public concerns over the safety of genetically edited crops (Wang *et al*., 2020).

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