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Introductory Chapter: Protecting Rice Grains in the Post-Genomic Era: Are We There Yet?

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1. Introduction

Rice (*Oryza sativa* L.) was domesticated roughly 10,000–14,000 years ago. Today, rice is the most widely grown food crop in approximately 113 countries, providing a major dietary caloric and protein supply (**Figure 1**).

Rice has been a staple food source for many cultures globally and is particularly critical for developing countries where other food resources are limited. Rice
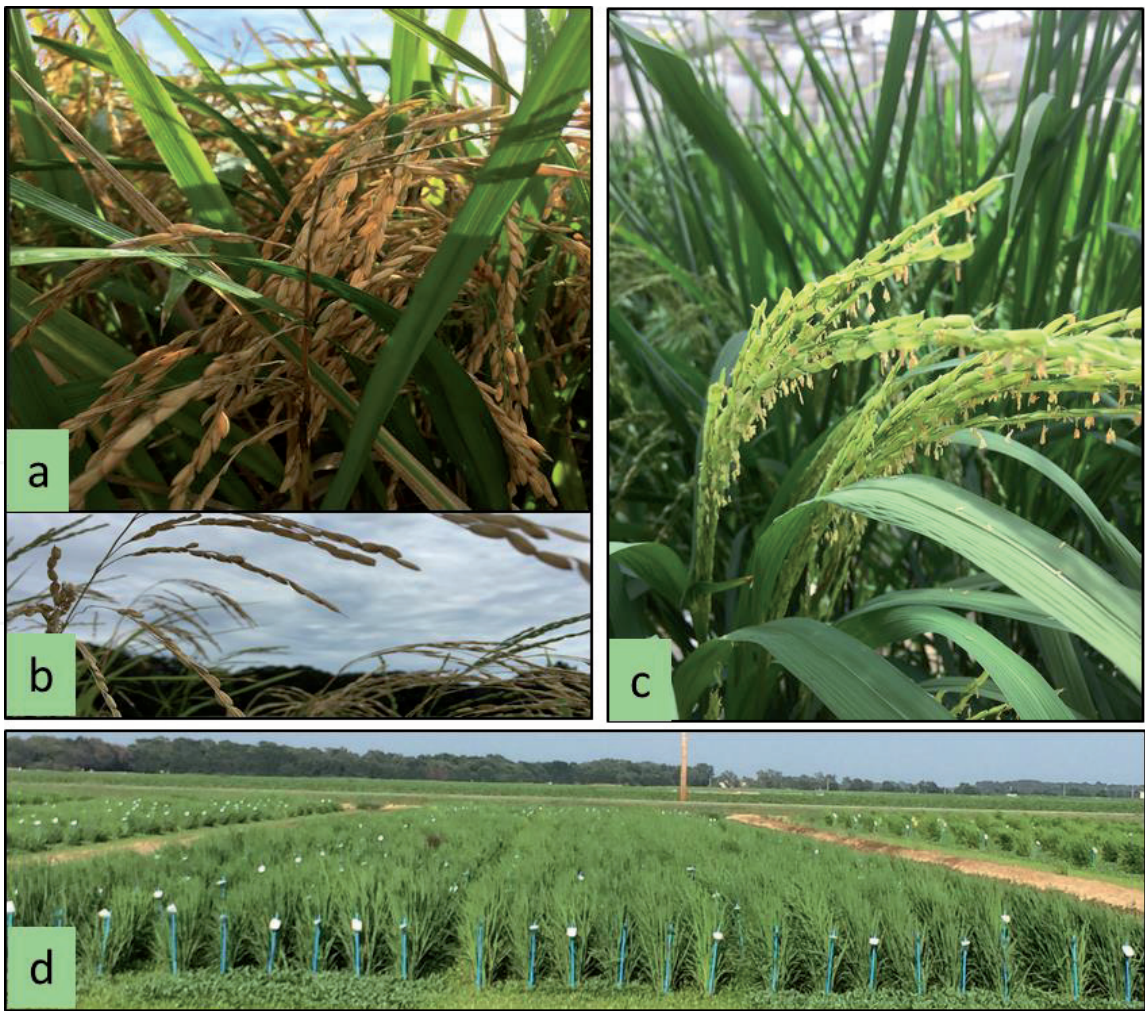

Figure 1.
Pictures showing rice plants grown in the USA, 2018. Blast-resistant rice breeding and differential lines grown in Crowley, Louisiana (a, b). Blast-resistant plants and two mapping populations with blast resistance genes grown in a greenhouse and a field, respectively, Stuttgart, Arkansas, USA (c, d). Pictures were taken from rice grown in experimental stations in the USA with an iPhone.
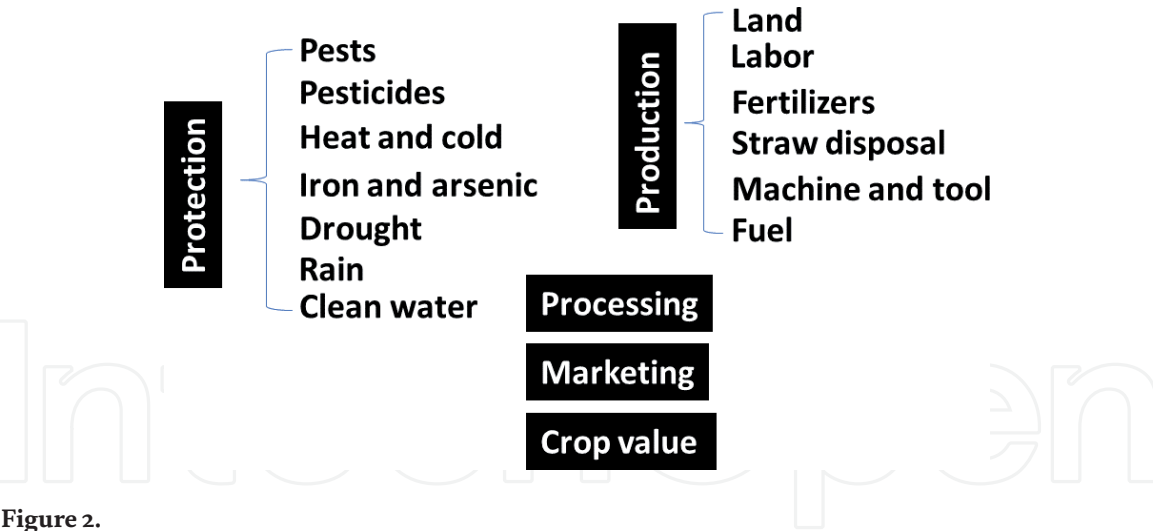
Figure 2.
Diagram showing the major challenges of rice protection.

grains feed more than 3.5 billion people [1]. Rice germinates under a wide range of temperatures, from 10 to 40°C, and requires about 3–6 months to mature. There are two primary methods of rice production: transplanting of rice seedlings from a nursery to paddy rice fields to ensure uniformity and weed control and sowing seeds in a rice field directly to conserve labor. Rice production was particularly enhanced during the green revolution through the deployment of high-yielding uniform rice varieties, especially semidwarf rice. However, the wide deployment of well-adapted uniform varieties consequently made rice more vulnerable to both biotic and abiotic stressors (**Figure 2**). Many major rice-growing countries today including China, India, Japan, Korea, Brazil, the USA, the Philippines, and Thailand have been experiencing old and new obstacles that inhibit the stable production of rice. As such, the question of whether the current methods of rice cultivation are sufficient, or whether we are there yet, or have plateaued, remains unanswered.

2. Major challenges and opportunities for rice grains

Major challenges and opportunities for rice grains are embedded during rice propagation, protection, postharvest pest management, processing, and marketing (**Figure 2**). First, rice diseases have had a major impact on the stability of rice production. For example, the famine in Bengal, India, in 1942 was mainly due to rice brown spot disease [2], and a rice blast epidemic in Korea caused a major food shortage in the 1970s [3]. The most common rice diseases are caused by fungal and bacterial pathogens. Fungal diseases include rice blast, sheath blight, false smut, rice brown spot, rice stackburn, leaf smut (**Figure 3**), and grain discoloration diseases include rice blast, bacterial panicle blight, false smut, and kernel smut (**Figure 4**).

Bacterial diseases include bacterial blight and bacterial panicle blight (**Figure 4c**). Insects are another type of stressor for rice production, whose importance varies with the country, location, and time. Rice water weevil (*Lissorhoptrus oryzophilus*), rice stink bug (*Oebalus pugnax*), fall armyworm (*Spodoptera frugiperda*), rice stalk borer (*Chilo plejadellus*), and grasshoppers (*Orthoptera*) are commonly found in the southern USA. For decades, the common remedy for pest management has been an increased application of pesticides and the alteration of cultural practices with limited use of natural genetic resistance. Most rice pathogens and insects adapt to their food sources through genetic changes, resulting
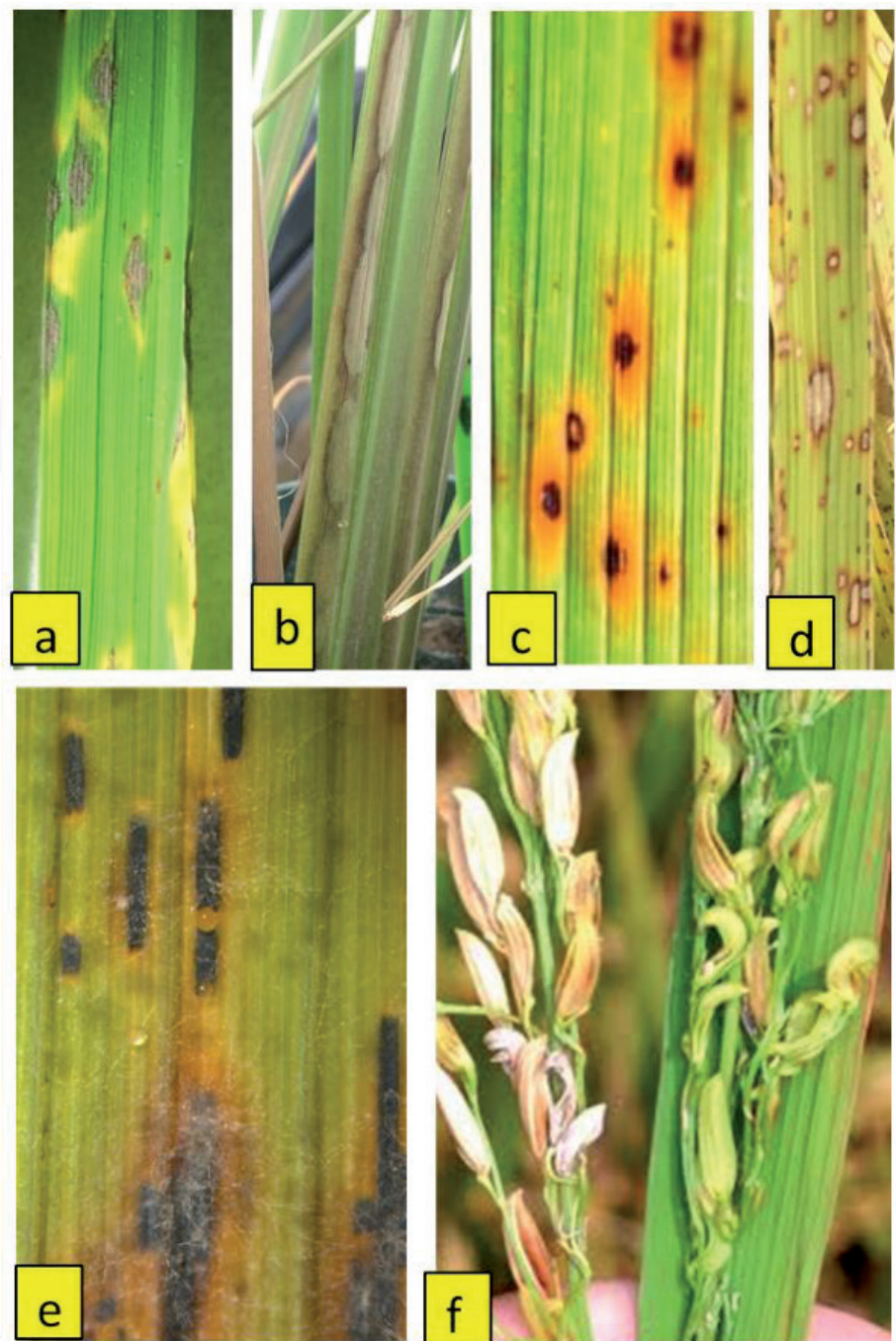
Figure 3.
Photographs showing examples of rice diseases on leaf, sheath, and grains. (a) Leaf blast caused by M. oryzae; (b) sheath blight caused by Rhizoctonia solani; (c) brown spot caused by Cochliobolus miyabeanus, called Helminthosporium leaf spot; (d) stackburn caused by Alternaria padwickii; (e) rice leaf smut caused by Entyloma oryzae; and (f) straighthead disorder. Pictures were taken from diseased plants under greenhouse and field conditions in Stuttgart, Arkansas, USA.

in more virulent races. Consequently, rice pests are becoming more resistant to pesticides and newly deployed resistance genes.

Rice thrives in a wide range of geographic and climatic regions, especially where many other crops would fail. As a semiaquatic crop, rice uniquely requires a lot of water as evident by its Chinese name, "water grain." A lack of sufficient clean water is problematic for producing healthy and safe rice as the presence of water is particularly critical during the rice vegetative and reproductive growth stages. There are numerous reasons for the current limit in clean water supply for rice production: depletion of groundwater, increased water usage by human consumption, and contamination due to improper disposal of industrial waste and pesticide
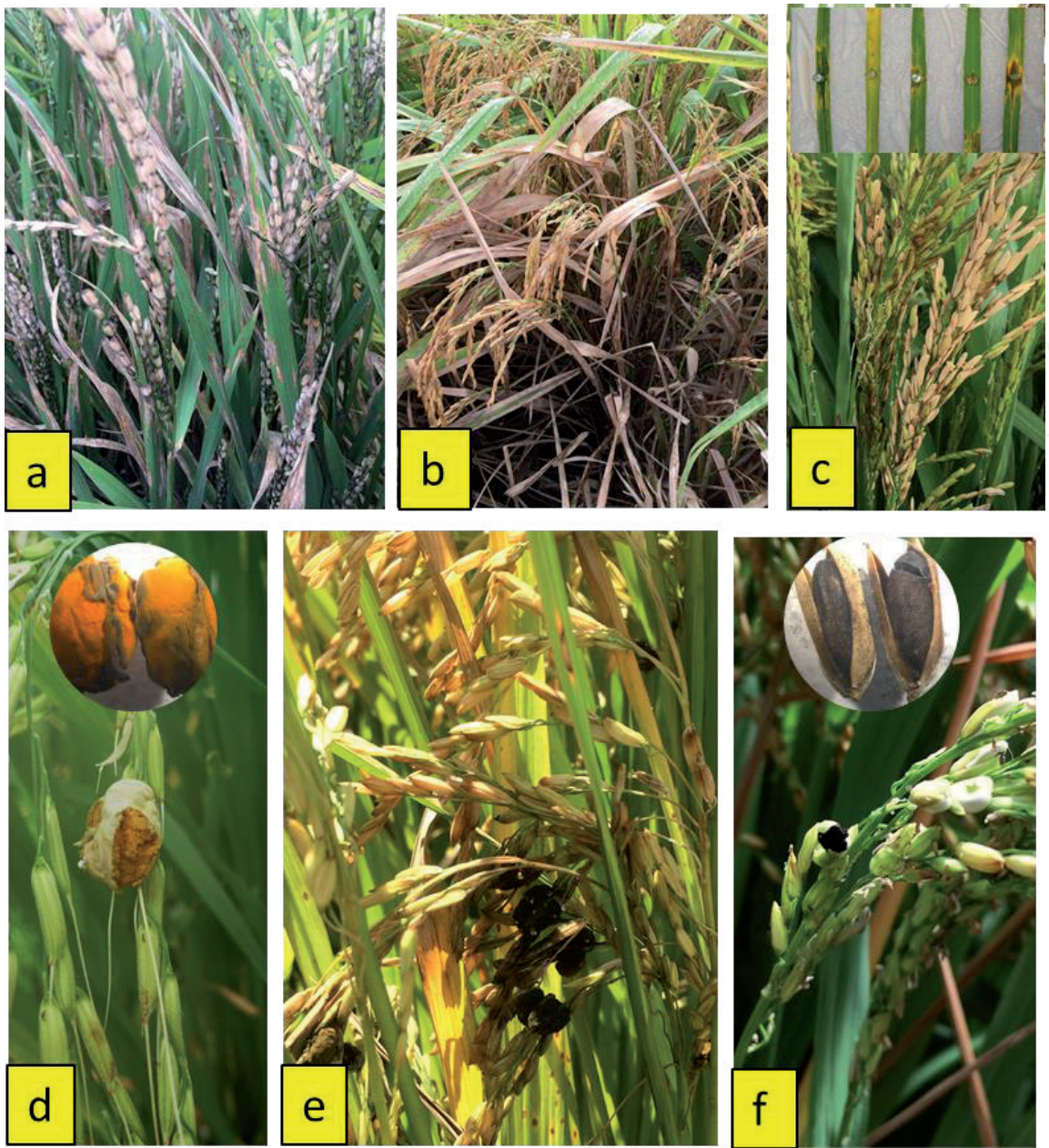
Figure 4.
Examples of rice diseases under field and greenhouse conditions. (a) Rice blast disease showing leaf and kernel blast; (b) sheath blight disease showing symptoms on leaf and stems; (c) bacterial panicle blight disease in a field (3 days after detached leaves from five susceptible rice varieties were inoculated with B. glumae), top; (d) rice false smut disease with two 2× enlarged detached smut balls in the top; (e) rice false smut disease in a field showing the late stage of false smut balls; (f) rice kernel smut with two 3× enlarged smut kernels on the top (all pictures were based on predicted symptoms of rice in greenhouses and fields in Crowley, Louisiana, and Stuttgart, Arkansas, USA).

contamination [4]. The abiotic stressors of rice include extreme temperatures during the seedling and reproductive stages; high concentrations of salt; soil heavy metals including cadmium (Cd), lead (Pb), and arsenic (As); and drought. Straighthead is the most common abiotic disorder in the USA (**Figure 3f**). However, the importance of abiotic stress varies with the region in which the rice is being grown.

It is evident that human life in the twenty-first century is much better than that of past centuries due to continued economic growth. As more people are being liberated from starvation, a demand for improved infrastructure to accommodate the incoming population has increased [5]. However, global urban land expansion often encroaches on croplands necessary for rice production. It was predicted that urban expansion will result in the loss of approximately 1.8–2.4% of croplands by 2030 [6]. Most of these land losses take place in the productive lands in top

rice-producing countries in Asia. As a result, the lost croplands were predicted to be responsible for 3–4% of worldwide crop production loss in 2000 [6].

Despite rice being a critical food crop for humanity, the monetary value of rice is extremely low. Farmers must grow rice in the interest of the continued survival of humanity, but increasing the crop value could cause an instability in food security and, as a result, society as well. Therefore, rice is not a competitive crop compared to many other nonessential agricultural products that generate higher income. Rice investment, as such, is among the lowest in many parts of the world. The current obvious challenge is developing methods of protecting rice grains despite its insufficient funding and resources. Today, the majority of rice is grown by small-scale farmers for local consumption [7]. The global market is less than 10% of total rice production with unique restrictions on the trade. Accordingly, the rice market is volatile and distorted [8]. Clearly, it is safe to conclude that human intervention is the most impacting factor that directly influences the outcomes of the interactions of rice with pests and with environmental conditions (**Figure 5**).

The mission of this book is not to solve the problems of yesterday but to solve those of today and tomorrow. It was estimated that rice yield must increase by more than 1.2% annually to meet the demand for food security as of 2005 [9]. The ability to sustainably grow rice is essential for the continued growth of the human population on the planet Earth. However, a shortage of labor will drive the adoption of direct seeding rather than transplanting and will impact the uniformity of space for each individual plant creating a microclimate conducive to disease epidemics. Additionally, water shortage will not only reduce the productive growth of rice plants but will also result in more crop losses caused by rice blast disease [10]. It is of utmost importance that each of us, everywhere, increases the efficiency of developing long-lasting resistance to stressors. In order to achieve this goal, a better understanding of the available scientific knowledge of rice host-pathogen interactions and its optimal environment (climate and human resources, marketing and rice utilization) will be needed.

Rice was the first food crop whose genome sequence was determined [11–13]. Shortly after, high-resolution genetic maps, expression maps, databases, and bioinformatics tools for rice research were developed [14–17]. These genomic resources were used to develop a basic molecular toolbox for rice breeding and crop
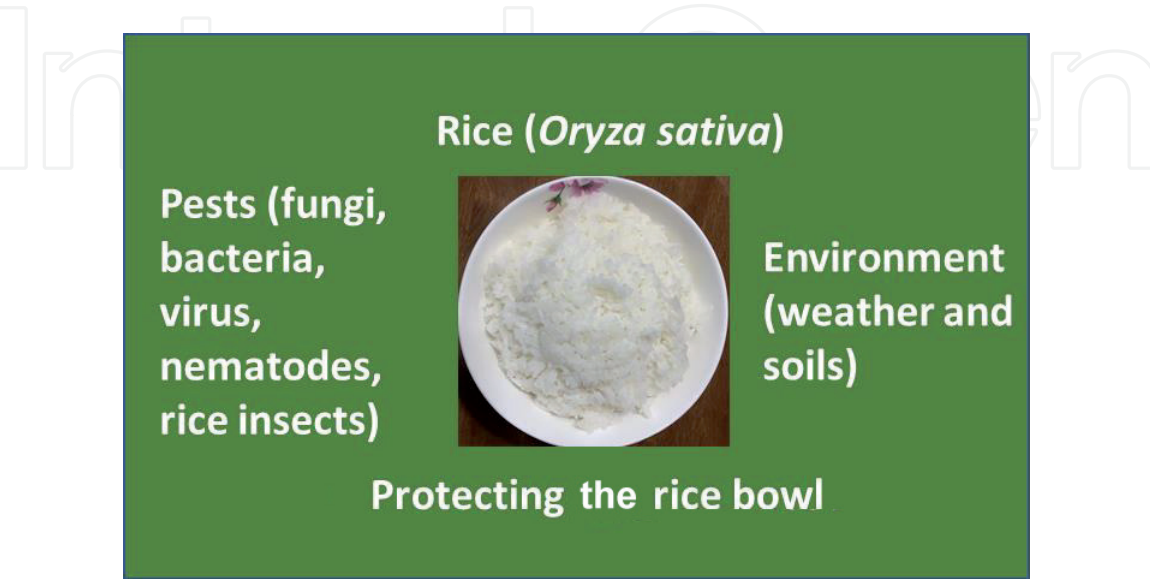

Figure 5.
Graphic presentation of primary factors that impact the rice bowl. The human intervention of host-pathogen-environment interactions is the key factor for securing the rice bowl. The Rice bowl at the center was taken with an iPhone.
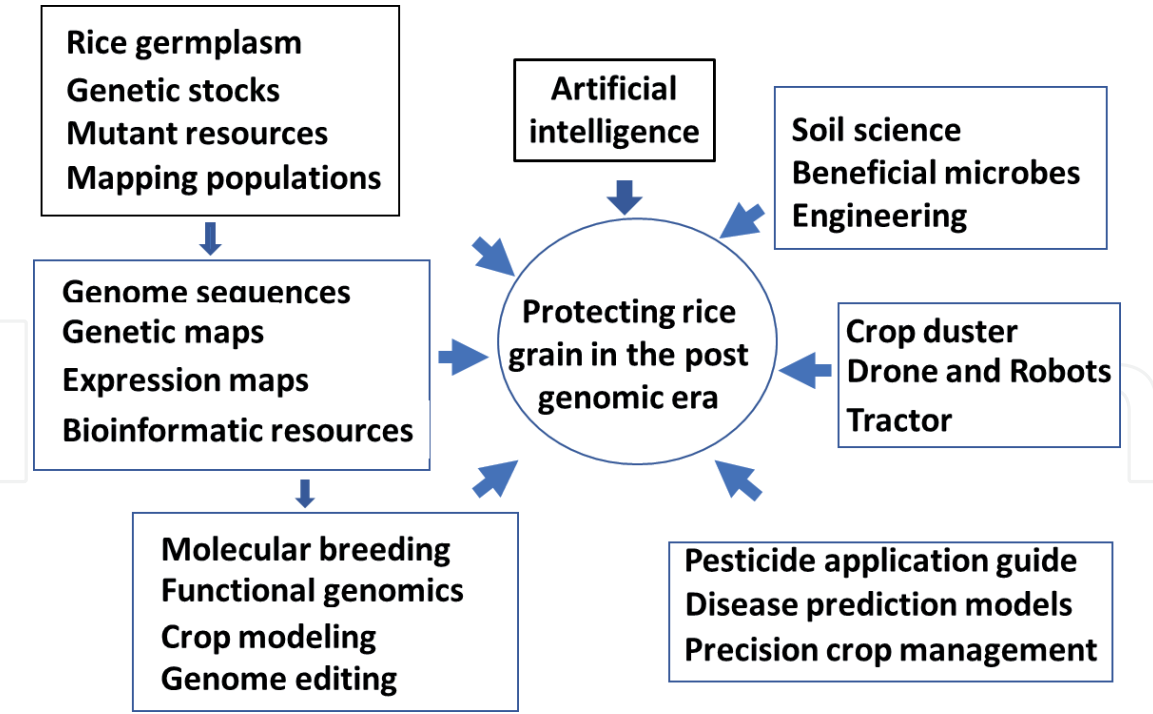
Figure 6.
Diagram showing tools and resources for protecting rice grains in the post-genomic era.

protection. Most recently, advances with next-generation DNA sequencing, coupled with rapidly developed bioinformatics tools, have paved a road for a deeper understanding of genetics and genomics of rice, pathogens, and host-pathogen interactions under changing environmental conditions [18, 19] (**Figure 6**).

The majority of chapters in this book describe the current update on plant resources, genomics, and methods for crop protection and production. This book also includes the methods to improve the market value of rice and better cultural practices and rice processing to ensure profits and marketability of rice grains. These tools, resources, and knowledge are implemented interchangeably into the current efforts to produce rice sustainably (**Figure 5**).

3. Conclusion

The book presents the power of genetics, genomics, and modern cultural practices for the production of one of the most important food crops, rice. The strategies and knowledge extracted from various rice resources, discovered resistance genes, observed mechanisms of host-pathogen interactions, cultural practices of rice labor, and rice processing and utilization of rice grains and husk are highlighted. It is anticipated that the knowledge in this book will guide stable rice production, protection, processing, and marketing. This book may also be useful for students and specialists who are interested in plant pathology, genetics, molecular biology, physiology, agronomy, and biological engineering.

Acknowledgements

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