Chapter 1
Challenges for Plant Breeding to Develop Biotic-Resistant Cultivars

Aluízio Borém and Roberto Fritsche-Neto

Abstract The fast world population growth and the increase in the *per capita* income, especially in the emerging nations referred to as BRIC countries (Brazil, Russia, India, China, and South Africa) has created huge pressure for the expansion of the agricultural growing area and the crop yields to meet the rising demand. Additionally, climate change has brought new challenges to agriculture to produce food, feed, fiber, and biofuels. To cope with these new challenges, plant breeding programs have to adopt new strategies to develop cultivars adapted to the new scenario. Experience shows that biotic stresses occur with different intensity in all agricultural areas around the world. The occurrence of insects, weeds, and diseases caused by fungus, bacterium, or virus may not be relevant in a specific year but they usually cause yields reduction in most of the years. The global warming has also shifted the paradigm of biotic stresses in most agricultural areas, especially in the tropical countries, bringing intense discussion on the scientific forums. This book has a collection of the most recent advances and discoveries applied to breeding for abiotic stresses, addressing epidemiological concepts, genetic resources, breeding methods, and molecular approaches geared to the development of resistant cultivars to biotic stresses. Written in an easy to understand style, and describing the breeding for biotic resistance step-by-step the reader will find this book as an excellent source of reference.

Keywords Climate change · Global warming · New diseases · Breeding for resistance · Biotechnology

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1.1 Introduction

In 1798, Thomas Malthus shocked the world with a catastrophic forecast: the human population growth was outstripping food, with predictions of famine and high rates of mortality in starving countries. Mr. Malthus lived in a period when the human population reached the first billion people. Since human evolved as a species, about 200,000 years ago, and for the primitive eras the human population increased slowly and gradually. It was only after the birth of agriculture, about 10,000 years ago that the human population growth increased more rapidly. After the Second World War the agriculture improved at a fast rate, making food supply abundant and population growth experience a new era of explosion.

Currently, the world population is over 7 billion people and the World Population Clock keeps registering the continuous increase in number of inhabitants (http://www.apolo11.com/populacao.php). Now the Malthusian specter is not banished and the question “would there be enough food for all?” is very up-to-date (Van Dam and Seidell 2007; Haddad et al. 2010; Haddad and Frankenberger 2003).

The population growth has also brought about the occupation of part of the agricultural areas with developments, roads, ports, power plants, and other facilities, making this a new Geological Era called Anthropocene, once the human activities are the major force molding the planet (Alexandratos 2006; Wright 2010). The challenges to provide food, feed fiber, and bioenergy to meet the world’s demand are requiring agricultural efficiency as never though before. On top of all that, global warming brings additional worries to agriculture.

In spite of Malthus predictions, the Anthropocene Era has been so far of relative food abundance, in particular in the developed countries. However, the demand for food has been increasing very rapidly, especially in the so-called BRIC countries (Brazil, Russia, India, China, and South Africa), where the living conditions are improving fast (FAO 2009, 2010; Fig. 1.1). For example, until very recently in Brazil, for many poor-resource people, lunch was basically rice, common bean, and cassava. Meat used to be a scarcer item in the diet of a significant part of the population. Today, most of the economic classes C and D eat food from animal origin, such as eggs, yogurt, cheese, and meat (Demeke et al. 2008; Barrett 2002; Bruinsma 2003). This improvement has been shared by millions of people, who have climbed the social ladder. Evidence is the rise of the economical classes in the last decade. According the World Bank, 50 million Brazilians have moved above the poverty line. The same tendency has been observed in most emerging countries, where the vegetarian diet, based on cereals and grains has been transformed into a much richer and varied diet, including food from livestock.

Food from livestock uses much more natural resources and causes a much higher pressure on the environment. For example, 1 hectare of soybean yields about 3 tons of grains. The same area with pasture produces only 46 kg of beef. Thus, it is easier to understand the huge pressure on agriculture nowadays. To cope with that pressure several new technologies have been brought to farm’s field along of the last decades: precision farming, mechanization, irrigation, pesticides,

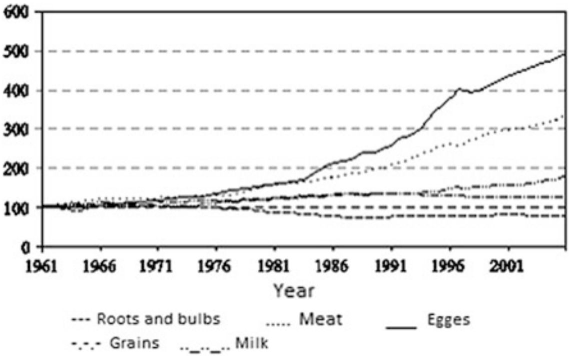

Fig. 1.1 *Per capita* consumption of five staple foods from 1961 to 2001. *Source* Agroanalysis (2011)

Fig. 1.2 Timeline, in human history related to food production

and many others. However, the biggest gain in crop yield came from plant breeding, developing new improved cultivars.

The time line on Fig. 1.2 shows some of the most relevant advances, discoveries, and events in human history related to food production. For example, the discovery of America in 1942 expanded the human diet to corn, potato, common beans, tomato, and many other species. In 1953, Watson and Crick discovered the chemical structure of DNA opening the door for the new era of genetics. With a better understanding of the genetics, plant breeding became more efficient in developing higher yielding- and more stress-resistant cultivars (Borém and Almeida 2011). For example, the Green Revolution was accomplished by Norman Borlaug in the 1960s by the introduction of the dwarf gene into new cultivars, prompting a significant yield increase in rice and wheat and other species production in countries that were facing starvation during the second half of the twentieth century. As a result of plant breeding, especially in the 1960s and 1970s, the productivity of the major crops increased faster than human population (Clay 2011).

Modern agriculture, using improved cultivars and good crop management resulted in increased yield in all crops (Green et al. 2005). These genetic gains were more relevant after the World War II, with the more ample adoption of improved cultivars. With the success of modern agriculture producing food in abundance and of high quality, the food prices dropped systematically along the last decades of the last century (Fuchs et al. 2009). The efficiency of agriculture was accomplished by a huge investment in research (Vencovsky and Ramalho 2006; Duvick et al. 2004). However, its efficiency in producing food in abundance brought a toll on it, with society taking it for granted, and agriculture research funds shrunken. This is especially a concern with the new challenges ahead for agriculture considering population growth and global warming.

Although the population that goes hungry every night has declined over the last 50 years, there is evidence that famine may surge in the medium and long run. Currently, 925 million people do not have access to the United Nations WHO macronutrients (carbohydrates, proteins and lipids) intake recommendations (FAO 2001, 2002; FAO Global Perspective Studies Unit 2007; WHO/FAO 2003). About another billion people have the so-called occult hunger, that is, bad nutrition, with hypovitaminosis and deficiency of minerals (Evans 1998; Borém and Rios 2011). Furthermore, about another billion inhabitants are consuming food in excess, with risks of overweight, obesity, and diabetes, showing the problem of food distribution in the world (Lopes et al. 2010; Sim et al. 2007).

Nowadays, agriculture has different and huge challenges, which will be even bigger in the coming decades due to the population increase. Population is expected to stabilize around 2050, when, according to the United Nations FAO it will reach 9.1 billion people. It is surprising that even before you finish reading this sentence, there will be three new inhabitants in the world, that is, 1 person every 3 s, 259.000 everyday, and over 7 million per month. This is shocking if compared that it took several thousand years for the world to reach 2 billion people and just in the next 25 years another 2 billion will be brought to the earth. Moreover, people are living longer and also migrating to urban areas (United Nations 2009; USDA 2009). Presently, half of the world's population lives in towns and cities, but by 2050 more than 70 % of population will live in urban areas. At that time there will be 26 megalopolises with over 10 million inhabitants (Clay 2011; Beddington 2010).

The challenges for agriculture in the coming years, due to increase in population size and climate change, are often debated in governmental forums (UK Government 2011). One of the hottest issues is if food production will meet the world demand. On Table 1.1 are the current food production and the estimated needs for 2025. Besides the larger population and the improved economic situation of people, especially in the emerging countries, the competition between land for food and for bioenergy will bring additional stress to food production. Energy demand should increase about 45 % in the next 25 years, and certain areas presently allocated for food production will be allocated for energy crops (Beddington 2010). It must also be realized that about 70 % of soils fit for agriculture have been already chosen for other uses (Clay 2011). According to this author, all agricultural food systems must double its yields by 2050. Otherwise, the World demand will not be met and the Malthusians predictions may come about at this time.

Table 1.1 Present production and estimated demand for food and fiber (in millions of tons)

Product	Production in 2005	Estimated demand in 2025	Additional needed production
Grains	2.219	3.140	921
Oil crops	595	751	156
Perennial crops	243	322	70
Annual crops	352	438	86
Coffee	8	10	2
Fiber	28	36	8
Wood	3.402	4.148	746

Source Adapted de Assad and Pelegrino (2007)

Table 1.2 Maximum grain yield (ton.ha^{-1}) recorded or estimated for different species

Specie	Yield	Source
Rice	10,5 (15,9)[a]	Boyer (1987)
Corn	23,2	Duvick and Cassman (1999)
Wheat	14,1	Tollenaar and Lee (2002)
Sorghum	20,1	Ort and Long (2003)
Soybean	7,3 (22,5)[b]	Ort and Long (2003)

[a] Estimated yield in the function of solar radiation during the growing season (Peng et al. 1999)
[b] Estimated yield in the function of the photosynthetic efficiency (Specht et al. 1999)

1.2 Potential Yield of Crop Species

Before discussing about potential yield it is necessary to address the meaning of biological efficiency, a variable concept according to its end use. For example, the production of food, feed, and fiber depend on the conversion solar energy. So yield should refer to the unit of the product per unit of absorbed solar energy. Crop scientists and economists, among other professionals, like to refer to it on the area unit, that is, amount of the product (kg or ton) per area unit (acre, hectare). The efficiency is, therefore, a relative measurement and it varies according to the environment, with the cultivar, and especially with its variations. Thus, a proper biological index could help plant breeders in obtaining cultivars with better efficiency in using natural available resources.

Potential yield can be defined as the yield obtained when the cultivar is grown with no environmental restrictions, that is, no biotic or abiotic stresses. In this condition, soil nutrients and water are not limiting factors and pests or weeds are effectively controlled (Evans and Fisher 1999). In general, it is difficult, or even impossible, to meet of those criteria to obtain the potential yield. There are reports in the literature about maximum productivity for many crop species. It can also be found in the literature yield potential in function of solar radiation. Those estimates are far beyond the maximum reported yield in commercial field conditions (Table 1.2). A crop yield potential is much larger than the biologic efficiency per area, that is, yield in ton.ha^{-1}, an index commonly used by crop scientists and farmers. Therefore, the genetic yield potential is much larger than yield recorded in any conditions. That fact occurs due to several environmental influences and management practices that negatively affect the crop performance, called stresses. If any of those factors reduces the biological efficiency it will reflect on the economical yield.

1.3 Biotic Stresses in Agriculture

The plant breeding success, especially in the last century (Denardi and Camilo 1998; Paterniani 1990), was due to selection for individuals with resistance or tolerance to stresses, instead of selection for higher yield potential, and most plant breeders expect this strategy will continue to be the focus of the breeding programs in the future (Tollenaar and Lee 2002).

The biotic stresses are one of the major causes of yield reduction on farmer's fields in most crops. Frequently, one can find reports of losses of up to 100 % of the yield. The most outstanding case of biotic stress in food insecurity occurred in Europe in 1845, especially in Ireland and England, when about 80 % of potato fields were lost due to *Phytophthora infestans*, etiological agent for potato blight. Due to this disaster more than 2 million people died hungry and many other migrated to other regions. Another case of an economic catastrophe was with the Corn Leaf Blight in the corn fields in the 1970s, when most farmers had significant losses due to susceptibility to *Helminthosporium maydis*.

Recently, some studies have shown that Soybean Asian Rust, in Brazil, was responsible for 37–67 % of yield reduction (Kumudini et al. 2008). This disease, from 2006 to 2011, caused US $4 billion income loss for soybean growers in Brazil. In Asia, the soybean losses due to this disease reached up to 80 % (Miles et al. 2003). Should a resistant cultivar be available, a large amount of fungicides with economical and environmental negative effects would not be need to be deployed in the soybean fields.

The spectrum of biotic stresses that may cause crop yield losses is large and diverse. For example, for common beans, Vieira (1983) reports over 45 virus, bacteria, fungi, and nematodes that may reduce crop yield in different regions and situations. Plant breeders have accomplished important success in developing biotic stress-resistant cultivars over the years. The introgression of disease resistance alleles has a stabilizing crop production from season to season. Protected from pests, cultivars can show most of its yield potential.

To complicate, most of the plant pathogens can present pathogenic races or biotypes. This poses an additional hurdle to breeding programs, once a new cultivar resistant to a specific pathogen race may be susceptible to others races. Therefore, when a pathogen race has a mutation and a new race emerges plant breeders have to initiate a new breeding effort to develop a resistant cultivar in an endless battle against the pathogen. Another problem is the shift of prevalent

Table 1.3 Estimated reduction of common bean yield due to diseases

Pathogen	Yield reduction (%)	Reference
Colletotrichum lindemuthianum	55	Vieira (1964)
Meloidogyne sp.	67	Freire and Ferraz (1977)
Phaeoisariopsis griseola	1–41	Santos Filho et al. (1978)
Uromycesphaseoli var. *typical*	21–42	Nasser (1976)
Bean golden mosaic virus	43–73	Vieira (1964)
Bean golden mosaic virus	100	Vieira (1964)

existing pathogenic races in a region, since they may also reduce the life span of a resistant cultivar that after a few growing seasons become susceptible.

Table 1.3 presents estimates of yield reduction in common bean, caused by several pathogens. Those estimates show the economic importance of diseases in food production, especially when large growing areas are considered. Thus, the development of disease-resistant cultivars has been a priority in many breeding programs.

It must also be recognized that the number of insects that causes yield reduction is large, including those that attack the crops during the growing season, feeding on leaves, pods, fruits, and roots. An additional class of insects that causes losses feeding on the harvested crop, like borer, weevils among others exists and causes significant food loss.

Historical evidences show that biotic stresses occur, in high or low intensity, in just all agricultural areas around the world. In some areas, the stresses caused by pests and weeds may not be relevant in a specific year, but they bounce back in the following years. Additionally, climate change is bringing new pests and weeds to relevance in crop production, especially in the tropical regions.

The predictions by the Intergovernmental Panel on Climate Change (IPCC 2007) gave birth to several speculations of what one could expect in the coming decades. What drew more concern from society was food production and food security globally, as well as the agribusiness economic losses (Assad and Pelegrino 2007). Several simulations showed apprehensive scenarios and many governments are concerned about their food security (Lobell et al. 2008; Buntgen et al. 2011).

Overall, global warming should bring larger incidence of insects, diseases, and weeds on farms around the world. Some biotic stresses that have been considered secondary in many crops until now will assume major relevance with climate change. An example is Angular Leaf Spot (*Pseudocercospora griseola*), which were considered a secondary disease of minor importance in most common bean growing areas in Brazil. But in the last years that changed and this disease is now one of the major biotic stresses for this crop.

Breeding efforts for developing insect-resistant cultivars have not been as effective as for disease resistance. However, some insect-resistant cultivars have been developed over the years, as against to *Empoasca kraemer*, *Diabrotica speciosa* and for post-harvest insects, as against to *Acanthoscelides obtectus* and *Zabrotes subfasciatus*. With the arrival of biotechnology, the development of insect-resistant cultivars has been one of the most active areas of research and with good success. For example, Bt cultivars resistant to Lepidoptera are a great success around the world and have contributed to the reduction of insecticide use in cotton, corn, soybean, and other species. Those resistant cultivars are a good example of achievement in breeding for biotic stress resistance.

It should also be realized that for a good crop, weeds must be controlled. Weeds can be defined as any species growing where it causes losses to the crop grown in that area.

Most large farmers use chemical weed control around the world, since it is efficient and has a competitive cost, when compared to other weed control methods. However, some farmers, especially in developing countries, have a short sight and are focused on immediate profit, using the same herbicide season after season. As it is well known, the use of a same herbicide on an area for several years will result in the selection of weed-resistant biotypes (Powles and Shaner 2001). As a consequence, the population of herbicide-resistant weeds has grown worldwide, becoming an agricultural problem for many farmers. One of the possible contributions of plant breeding to weed management is through allelopathy, the ability of a plant to produce chemical substances that affect other plants in a favorable or on an unfavorable manner, when released on the environment (Wu et al. 1998). The objective of most of those breeding programs target inhibiting weed germination or affect its growth.

Many breeding programs using biotechnology are developing cultivars tolerant to herbicides, such as soybean, corn, cotton, and colza tolerant to glyphosate; corn tolerant to imazaquin; and rice and soybean tolerant to ammonium glufosinate. The possibility to grow corn, cotton, sugarcane, and soybean free of weeds has been very attractive to most farmers around the world, especially due to its economic benefits.

The contribution of plant breeding throughout history in helping agriculture to produce food, feed, fiber, and fuel is very well documented in the scientific literature (Vencovsky and Ramalho 2006; Duvick et al. 2004). However, what will happen in the coming decades with the new challenging scenario will demand from breeders new and more efficient strategies to help agriculture solve the main challenge to humanity—food security (Costa 1974). The objective of this book was to collect and bring to its readers the most recent scientific achievements and the state of the art in breeding for biotic stresses, guiding breeders on their decisions and priority taking in their programs. In the following chapters, the reader will find the most relevant information to breed for fungus, bacterium, virus, nematode, and insect resistance and for weed management. In the other book *Plant Breeding for Abiotic Stress Tolerance* (Fritsche-Neto and Borém 2011); analogous aspects to abiotic stresses are addressed.

1.4 Perspectives

The United Nations estimates that around 2050 the world population will stabilize nearby 9.1 billion people. To make it even worse about 70 % of that population will be living in urban areas. At that time there will be 2–3 billion people with *per capita* income three times higher than presently, consuming twice as much as today. Consequently, it is clear that the food demand will continue to increase strongly in the coming decades.

Furthermore, there will be the negative effects of global warming/climate change. In this new setting the biotic stresses on crops will exacerbate. Consequently, the current knowledge about insect, disease, and weed management will be defied, requiring from plant scientists and especially from plant breeders new strategies, deep commitment, and hard- and interdisciplinary-work to develop biotic stress-resistant cultivars.

In the coming chapters, knowledgeable experts present the most recent advances in breeding methodologies, plant germplasm, and molecular biology applied to develop cultivars for different situations of biotic stresses.

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