Roberto Fritsche-Neto
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Preface

Practical experience shows that abiotic stresses occur at high or low intensity in just about all agricultural growing areas around the globe. In some regions the stress due to heat, drought, and mineral nutrition or even due to aluminum toxicity may not be present in a specific year, but this could change in the coming years. The consequences of the climate change for agriculture have caused concern for many policy makers around the world and it has been a hot topic in many scientific forums. The main apprehension is that the world may not be able to sustain its food production under the crescent abiotic stresses with global warming.

The organizers of this book have pulled together this publication aiming to cluster the most relevant scientific achievements and the state of the art in plant breeding and cultivars development for abiotic stresses.

Written by experts in different areas of abiotic stresses, in an easy to understand language, this book is an obligated reference for all interested in plant breeding and in the upcoming challenges that agriculture will face with climate change.

Roberto Fritsche-Neto
Aluízio Borém

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Chapter 1
Abiotic Stresses: Challenges for Plant Breeding in the Coming Decades

Aluízio Borém, Magno Antonio Patto Ramalho and Roberto Fritsche-Neto

Abstract Modern agriculture has been providing food, feed, fiber and more recently biofuel to meet the World́s demand. One of the bases of this modern agriculture is the improved cultivars, which are much higher yielder than ancient ones. The scientific literature documents the significant contribution of plant breeding to agriculture and finally food production worldwide. Now-a-days, agriculture has new and huge challenges, due to population growth, the pressure on agriculture liability on the environmental conservation, and climate change. To cope with these new challenges, many plant breeding programs have reoriented their breeding scope to stress tolerance in the last years. So, in this book, experts on plant physiology and on plant breeding presents the most recent advances and discoveries applied to abiotic stresses, discussing the new physiological concepts, breeding methods, and modern molecular biological approaches to develop improved cultivars tolerant to most sorts of abiotic stress.

Keywords Climate change · Global warming · Improved cultivars · Breeding for draught · Biotechnology

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1.1 Introduction

Agriculture was the most important event in the man's history, changing his nomadic lifestyle to start to settle in communities. Archeological evidences suggest that agriculture began about 10,000–12,000 years ago. With agriculture, man accelerated his influence in the environment, especially by substituting the native and diverse flora by the species of their preference or needs.

At the beginning of the nineteenth century, there was an increasing concern that the rapid growth of the population could result food shortage and the poor-resource population would go famine. The most famous writing about this was by the economist Thomas Malthus, who said that the population increase according to a geometric progression while the food supply would increase according to an arithmetic progression. While Malthus model was correct, he did consider the agricultural technology development such as use of fertilizers and especially the adoption of genetically improved cultivars. Therefore, even with the population increasing to 4.68 billion people during the twentieth century, food was available to meet the demand, except for short periods of time. It is important to say that today hunger is mainly due to wealth distribution and not due to food scarcity.

With modern agriculture using improved cultivars and good crop management, crop yield has been raised in just all agronomic species. This progress was more evident after the Second World War, with the wide adoption of improved cultivars, fertilization, insecticides, and fungicides. With the success of modern agriculture to produce food in quantity and quality, the prices of food dropped during the twentieth century. The food abundance, as a result of agricultural technology, had its own toll; society lost the sense that agriculture had importance. With plenty of food at low prices, many other areas of the human knowledge start to drain a significant part of the investments in R&D, and today the agricultural research lives a huge dilemma; how to develop the technology for the coming decades, especially with the new challenges with climate change. One of the signs of the shortage of investments for agricultural research is the small number of newly trained plant breeders in the last decade, in spite of plant breeding's contribution to increase food production worldwide (Vencovsky and Ramalho 2006; Duvick et al. 2004).

Although the population that goes hungry has been reduced in the last 50 years, there are evidences that it could spike in the medium and long run. Currently, about 925 million people do not have access to the minimum daily amount of food recommended by United Nations WHO considering the macronutrients (carbohydrates, proteins, and lipids). It is estimated that another 1 billion people have the occult hunger, that is, have bad nutrition with deficiency of vitamins and minerals (Evans, 1998; Borém and Rios 2011). On the other hand, nearly another 1 billion people is consuming food in excess with risk of obesity and diabetes.

Nowadays, agriculture has new and huge challenges, which tend to be even bigger in coming years. This is due to the fact that the population is supposed to increase up to 2050, when according to the United Nation FAO the world population will stabilize reaching 9.1 billion inhabitants. The population increase will have profound

Table 1.1 World food and fiber production demand in 2005 and 2025 (in millions of tons)

Product	Production in 2005	Demand in 2025	Additional production
Grains	2.219,40	3.140,40	921
Oily grains	595,05	750,97	155,96
Perennial crops	242,81	321,99	70,18
Annual crops	352,2	437,98	85,78
Coffee	7,72	9,4	1,68
Fibers	28,5	36,37	7,87
Timber	3.401,90	4.148,40	746,5

Source Adapted from Agroanalysis (2007)

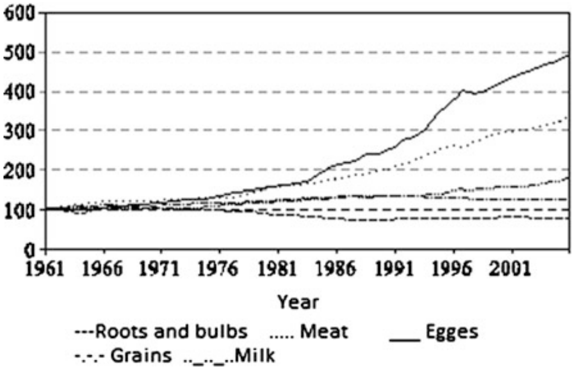

Fig. 1.1 *Per capita* consumption of five food products in emerging countries from 1996 to 2001. *Source* Agroanalysis (2011)

outcomes to our planet. It is surprising that, even before this sentence is complete, there will be another three inhabitants on the Earth, that is, a new person is born every three seconds, 259,000 new inhabitants per day, 7 million per month. It is worth noting that it took several million years for the Earth to reach its first 2 billion people, and that another 2 billion will be brought just in the next 25 years. Additionally, people are living longer and also moving from the country side to urban areas. Half of the world population currently live in cities and small towns, but this number should increase up to 60 % by 2030, when it is supposed to exist 26 cities with population over 10 million people (Beddington 2010).

The challenges to be faced by man due to the population increase in the coming decades are various and often debated (UK Government 2011). One of them is how to provide food to meet the demand. On Table 1.1 is listed the world food production and demand in 2005 and in 2025. The increased demand for food is not only due to population increase, but also due to many other factors, among them is the increase in population wealth, especially in the emerging countries called BRICS (Brazil, Russia, India, China, and South Africa), resulting in demand for a more diverse and rich diet (Fao 2009, 2010; Fig. 1.1a). It is well known that an increase in the per capita income results in an increase in food demand, and the BRICS countries represent 40 % of the world population and nearly 18 % world economy.

Another factor pressing the food production is the competition between the areas designed for bioenergy production. The demand for bioenergy should increase 45 % in the next 25 years, and growing areas used for grain will be allocated to sugarcane, jatropha, and other energy crops (Mitchel 2008; Beddington 2010).

The pressure on agriculture will be even greater due to its environmental liability. Among the environmental aspects used as input in agricultural water deserves a special attention. It is estimated that 70 % of the drinkable water is currently used for irrigation (Chris and Briscoe 2001). Therefore, water must be used more efficiently. Additionally, it is estimated that many areas around the world will have less soil water, creating the need for irrigation to be more widespread and intense in many growing areas.

The renewable agriculture inputs will also become scarcer and more costly. For example, Brazil uses 2.5 millions of nitrogen, i.e., 2.5 % of the world consumption, and 3.7 million of K_2O, making up to 13.9 % of world consumption.

To complicate the scenario even more, there is an increasing pressure for lowering the CO_2 emission (Wright 2010) and it is regarded agriculture will suffer most (Lobell et al. 2003; Assad and Pelegrino 2007). To cope with this scenario many marginal areas will be added to the agricultural system. Many of those marginal areas have aluminum toxicity, salinity, or other abiotic stresses, demanding for cultivars adapted to such constrains.

Most of the agricultural systems are not sustainable, mainly due to the intense use of non-renewable resources reinforcing the feeling for more stress-tolerant cultivars.

The lack of sustainability will make the insects, diseases, weeds, and biotic stresses more prevalent and severe. To deal with those challenges, more planning and new technology is necessary. Besides the traditional techniques and breeding methods, Biotechnology (Quam 2009; Borém and Almeida 2011) and other emerging technologies, such as Nanotechnology (Alexandratos 2006; Bruinsma 2009) must be adopted.

The contribution of plant breeding to increase food, feed, fiber, and biofuel production (Vencovsky and Ramalho 2006; Duvick et al. 2004) is well documented. Nevertheless, whatever happens in the coming decade, plant breeders will have to devote profound dedication and deep scientific knowledge to keep pace with the increasing food demand in a hungry world. The main goal of this chapter is to address the scope of abiotic stresses for agriculture and how to cope with them, helping plant breeders to establish right priorities and develop adequate cultivars.

1.2 Crop Yield Potential

Before discussing what potential yield is, it is needed to define biologic efficiency. The concept of biologic efficiency varies with the crop species and situations. For example, for food, feed, and fiber biologic efficiency depends on the solar energy conversion. Yield should reflect the unit of the product per unit of absorbed solar energy. Crop scientists and economists, among others, prefer to associate biologic efficiency to unit of area, such as amount of the product (kg, tons) per area unit

Table 1.2 Record grain yield (ton.ha^{-1}) in different crop species

Species	Productivity	Source
Rice	10.5 (15.9)[a]	Boyer (1987)
Corn	23.2	Dwick 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] Yield estimated in function of solar radiation during the growing season (Peng et al.1999)
[b] Yield estimated in function of photosynthetic efficiency (Specht et al. 1999)

(acre, hectare). In this book and in most situations for plant breeders, the biologic efficiency is measured by amount of the product per unit of applied resources. In many cases, it is estimated per unit of the following resources land, water, energy, fertilizer, pesticides, capital, and machinery. The efficiency is, therefore, relative and varies with the environment and the cultivar. Thus, the use of a biologic index can help plant breeders to develop cultivars with higher efficiency of the use of natural resources.

Yield potential is the maximum production when the cultivar is grown in a favorable environment, that is, in the absence of limiting factors and where it is completely adapted. In this environment, mineral nutrients and water are not yield-limiting factors and pests and weeds are effectively controlled, i.e., the plant development takes place with no stress (Evans and Fisher, Evans and Fisher 1999). In general, it is difficult or even impossible to grow a crop under conditions to obtain the maximum yield. However, there are several reports on the literature on maximum yield for many crop species. There are also reports on potential yield in function of the solar radiation. All those estimates are much higher than those estimates obtained in practice (Table 1.2). The yield potential is substantially higher than the biologic yield per land unit, i.e., yield in ton.ha^{-1}, a unit often used by agronomists. Therefore, the cultivar genetic potential is much higher than that obtained in real life. Why does that occur? As previously stated, each environmental factor that negatively affects the plant development is called *stress*. There are many environmental and/or management factors that have profound impact on plant growth, and the restriction of one or more of those factors diminishes the biologic efficiency with reflection on the productivity.

The genetic gain for most crops, if not all, obtained in the last century, was due to plant selection targeting tolerance toward stresses, instead of aiming higher yield potential (Tollenaar and Wu 1999; Tollenaar and Lee 2002). It is believed that the same strategy will continue to be used for breeding in near future.

Boyer (1982) reports the main causes of crop failure in the USA. It can be observed that the abiotic stresses are responsible for up to 89 % of all crop failure, and among them drought is responsible for more than 40 % of the losses (Table 1.3).

It must be realized that stresses in tropical growing areas tend to be much more prevalent and intense than in temperate regions. Paterniani (1990) draws a parallel between environments' growing factors in those regions where corn is grown (Table 1.4). It is noteworthy that stresses for agriculture are substantially more

Table 1.3 The main reasons for crop loses, in percentages, where insurance was granted in the USA

Reason of loss	Loss (%)
Drought	40.8
Flooding	18.2
Cold	13.8
Hail	11.3
Wind	7.0
Insects	4.5
Diseases	2.7
Others	1.5

Source Adapted from Ort and Long (2003)

Table 1.4 Characteristics of corn grown in tropical and temperate regions

Characteristics	Temperate	Tropical
Annual Climatic variation	Relatively stable	Unpredictable
Annual rain variation	Relatively uniform	Variable
Rain among regions	Relatively uniform	Variable
Photoperiod	Long days	Short days
Night Temperature	Cold	Warm
Soil conditions	Usually favorable	Usually adverse
Sowing period	Restrict/well defined	Highly variable/all year long
Growing period	Well defined	Highly variable
Germination conditions	Cold soil/soil fungi present	Soil insects present
Weed infection	Medium infestation	High infestation
Grain insects	Low infestation	High infestation starting in the field

Source Adapted from Paterniani (1990)

adverse in tropical regions than in temperate regions. The author compares, for example, the rain precipitation in Piracicaba, SP (Brazil) and in Ames. IA (USA). In Ames, the rain in July and August, months when the crop flowers, averaged 92.6 mm ± 35.5 and 97.6 mm ± 40.7, respectively. In Piracicaba, during the months when the crop is flowering, i.e., December and January, the average rain is 218.9 mm ± 75.9 and 216 mm ± 94.1, respectively. At first, those estimates suggest that water availability is much more favorable in Piracicaba. However, the rain distribution in Piracicaba is much more erratic. In this region, short periods of intense rain occur with low accumulation of the water in the soil. Those periods of heavy rain usually are followed by long periods with no precipitation.

The author did not consider the environmental factors that may be controlled by farmers, such as mineral nutrition. Thus, it is worth noting the importance of abiotic stresses in the region in the Globe where food production is expanding at higher rate.

The main objective of plant breeding is to develop improved cultivars. Usually, they are developed with more drought tolerance or with resistance to any other stress, but breeders are now also striving to develop cultivars more efficient in using limiting environmental factors.

1.3 Plant Breeding and Stresses Caused by Climate Change

Practical experience shows that abiotic stresses occur at high or low intensity in just about all agricultural growing areas around the Globe. In some regions, the stress due to drought, heat, and mineral nutrition or even due to aluminum toxicity may not be present in a specific year, but this could change in the coming years. The consequences of the climate change for agriculture have caused concern for many policy makers and been a hot topic and many scientific forums (Ramalho et al. 2009).The main apprehension is that the world may lack ability to sustain its food production under the increasing abiotic stresses with Global Warming.

Climate change is expected to bring additional challenges agriculture, already under pressure for higher productions to satisfy the crescent demand for food. Climate change will affect the development of new crop cultivars. Heavy rains, long droughts, intense heat will become more frequent and extreme, increasing volatility of crop production and food security. Food production is expected to be also affected by sea currents and ocean temperature. One could initially think that the increase of atmospheric CO_2, the raw matter for plants to grow, could foster yield increase. However, the increase of atmospheric CO_2 side effects will offset any benefits. Public policies for mitigation of climate change will also affect how agriculture is done. It is estimated that agriculture is responsible for roughly 10–12 % of all greenhouse gas emissions. By international accords greenhouse gas must be reduced by 2050 to 50–60 % of current levels, to avoid more serious impacts on the environment (Garnett 2008). The challenge is, therefore, feed the world meeting the environmental agenda (Fuchs et al. 2009).

Before the Industrial Revolution, the atmospheric CO_2 concentration was 280 ppm and today it is 384 ppm (IPCC 2007). It is expected that this carbonic gas concentration will reach between 720 and 1.030 ppm by 2100, and its consequence for agriculture, via Global Warming, will be even more alarming.

According to the perspectives on climate change presented by the Intergovernmental Panel on Climate Change (IPCC 2007) there has been many speculations of what will happen in the coming decades. The most striking aspect is the effects of the climate change on agriculture and its impact on food security, as well as on the economic losses in agribusiness (Assad and Pelegrino 2007). Several models have been developed showing how climate changes may occur and how it may bring adverse effects on agriculture (Lobell et al. 2008; Buntgen et al. 2011).

Some scientists argue that, if greenhouse gas emission continues at present levels, the world temperature would increase between 2.5 and 4.3 °C by 2099 (Christensen et al. 2007). In spite of the dramatic negative effects of Global Warming, in some regions the temperature increase may have a temporary benefit. In high latitude regions crops like corn, wheat, and rice may benefit from warmer climate due to higher CO_2 concentration and rain precipitation (Easterling et al. 2007). These same authors, however, suggest that in regions of low latitude, in the tropics, the increase in temperature will reduce yield. It is believed by some scientist that yield for corn and soybean in the USA maybe reduced by 30–46 % before the end of the present century if the current scenario persists (Kucharik and Serbin 2008).

In general, Global Warming may bring many adverse effects, such as accelerated plant growth, reduced plant phenological cycle, and increasing floral abortion and grain filling among others. Wahid et al. (2007) presents an in-depth review about Global Warming outcome for agriculture. Rain precipitation will be altered in quantity and distribution with bad consequences to plant growth as described in Chap. 6 More problems due to insects and other biotic stresses also expected. In Brazil, agricultural growing zones will have profound changes. For example, the coffee crop grown in many Minas Gerais State regions will move southward.

Arisworth and Ort (2010) discuss several physiological and management alternatives that may be considered to offset the adverse effects of Global Warming on agriculture and help it keep pace with the world demand for food, feed, fiber, and fuel. Some scientists believe that the climate change will be so drastic that currently available technologies may be ineffective. Assad and Pinto (2008), for example, suggested that it is possible that the speed with which climate changes occur makes the conventional methodologies in agriculture become obsolete and ineffective to allow agriculture to cope with the coming challenges.

The historical contribution of plant breeding to agriculture may suggest that those pessimistic forecasts could be avoided. For example, cauliflower, a species adapted to temperate climate has been bred in Brazil for heat tolerance. Up to the 1970s cauliflower was grown in high altitude regions in Rio de Janeiro State. The plant breeder Marcelo Dias introduced heat tolerance from different plant introductions and after a few selection cycles he developed the cultivar Piracicaba Precoce 1. This cultivar allowed this crop to be planted into previously marginal regions for this species. Today, cauliflower is grown in areas with mean temperature much higher than what it is expected to have with Global Warming, showing that plant breeding has a great potential for man to deal with the upcoming challenges.

Carrot is another good example of breeding for heat tolerance in the tropics. Similarly to what happened to cauliflower, in Brazil carrots were grown only in the Brazilian southern states up to the 1970s; but after Embrapa, the Brazilian agency for agricultural research identified carrot populations with heat tolerance; it launched the cultivar Tropical (Costa 1974) that broaden the adaptation region for carrots all over the country (Vieira 1976).

The last example among many other well-known ones is the heat tolerant apple cultivars that also developed in Brazil. Until 1970 all apples sold in Brazil were imported from Argentina and other countries, once the cultivars available in country were not well adapted. Apple cultivars require a minimum of 800 h of hibernation with temperatures under 7.2 °C, a condition just about inexistent in Brazil. Breeding programs targeting clonal selection developed cultivars with a much shorter hibernation requirement. Table 1.5 presents a list of apple clones developed up to 1988, showing cultivars substantially more tolerant to high temperatures (Denardi and Camilo 1998). It was also remarkable that this breeding progress followed by adequate crop management allow this crop in Brazil. Brazil

Table 1.5 Apple cultivars developed in Brazil

Princesa	400–500 h
Primicia	600–650 h
Catarina	>800 h
Baronesa	500–500 h
Condessa	350–400 h
Lisgala	>800 h—Mutation on cv. Gala
Fugi Suprema	>800 h—Mutation on cv. Gala

Source Adapted from Dernard and Camilo (1998)

today is self-sufficient in apple production and also exports this fruit to the European market.

It is important to realize, in the scenario of climate change that plant breeding can and will give an important tool for food security. The development of cultivars adapted to abiotic stresses is the best and most sustainable alternative to support agriculture today and in the future.

1.4 Plant Breeding and the Soil Abiotic Stresses

The soil has been called the *life's placenta*, since it is the source of all plants, which feed the ecosystem (Rao and Cramer 2003). Therefore, the lack or excess of the mineral nutrients in the soil affects the plant development. Soil stresses come about for many different reasons, such as poor soil management, soil genesis, etc.

Many management technologies have been developed to counterpoint stress from soil. For example, in many countries no-till has been widely adopted by farmers. The conventional planting system involves the use of moldboard plow for primary tillage followed by several secondary tillage using disc harrow, and for each 1 ton of corn harvest using this obsolete but still used system it lost 5 tons of top soil due to erosion (Paterniani 1990). With this erosion the soil loses most of its nutrients and the organic matter. Additionally, erosion causes other problems such as sedimentation of soil particles in rivers. In the no-till system the seeds are placed directly into the previous season's crop residue, reducing soil erosion.

One of the most important factors for the great grain yield gains in the 1950s was the use of chemical fertilizers especially in the developing countries. However, plants need six nutrients in larger quantities, called macronutrients and eight in smaller amounts, called micronutrients, the emphasis in this book will be on just two macronutrients: nitrogen and phosphorous, due their shortage and high costs. So, development of cultivars with better nitrogen and phosphorous use efficiency are essential for agriculture. Chapter 4 and 5 address different strategies for cultivar development by those traits.

High soil salinity is also a serious problem in many regions around the world. Salinity in general is caused by sodium salts, in special sodium chlorite, which causes severe problem to most crops. According to the FAO Land and Plant Nutrition Management Service, the more than 6 % of world's land is affected by

Table 1.6 World distribution of soil salinity, in million hectares

Regions	Total area	Saline soils		Sodic soils	
	Mha	Mha	%	Mha	%
Africa	1,899	39	2.0	34	1.8
Asia, the Pacific, and Australia	3,107	195	6.3	249	8.0
Europe	2,011	7	0.3	73	3.6
Latin America	2,039	61	3.0	51	2.5
Near East	1,802	92	5.1	14	0.8
North America	1,924	5	0.2	15	0.8
Total	12,781	397	3.1	434	3.4

Source FAO Land and Plant Nutrition Management Service

salinity or sodicity (Table 1.6), comprising over 400 million hectares. Of the current 230 million ha of irrigated land, 45 million ha are salt-affected.

Plant response to salinity involve modification in several physiological and biochemical processes. The plant's ability of detoxification from free salt ions requires a lot of energy, but it is the best way to grow susceptible crops in marginal due to salinity. Molecular genetics has provided new insights about plant tolerance to salinity. A cell type-specific expression of *AtHKT1;1*, a sodium transporter, has been shown to improve sodium (Na^+) exclusion and salinity tolerance in Arabidopsis (Plett et al. 2010). The authors found that, in the transgenic Arabidopsis plants overexpressing *AtHKT1;1* in the cortex and epidermis, the native *AtHKT1;1* gene responsible for Na^+ retrieval from the transpiration stream, was also unregulated. Extra Na^+ retrieved from the xylem was stored in the outer root cells and was correlated with a significant increase in expression of the vacuolar pyrophosphatases (in Arabidopsis and rice) the activity of which would be necessary to move the additional stored Na^+ into the vacuoles of these cells. This and many other recent studies present important steps in the development of salinity tolerant crops. This topic will be covered on Chap. 7.

When soil is acidic, which is with low pH, aluminum is dissolved in the soil solution and becomes toxic to most plants. Aluminum toxicity limits crop production in as much as half the world's arable land, mostly in developing countries in Africa, Asia, and South America. In Brazil, it comprises 25 % of all agricultural area. Aluminum toxicity affects root growth, reducing the plant ability to exploit the soil water and nutrients. Many biotechnology groups are cloning aluminum-tolerant genes and expect to have tolerant varieties. Breeding for aluminum toxicity tolerance will be discussed in depth in Chap. 8.

1.5 Perspectives

According to a panel of experts by United Nations the world's population will reach 9.1 billion people around 2050. The challenges for agriculture and especially for food production are huge, requiring from plant breeders' high dedication and solid knowledge to develop cultivars fit for those challenges. In the next chapters, different experts will address the most relevant achievements and breeding methodologies applied to cultivar development to produce under abiotic stresses.

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