



## REVIEW

# Genetic plant improvement and climate changes

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**ABSTRACT** - *The consequences of climate change for the agribusiness in Brazil have been widely debated. The issue is discussed in this publication to show the expected problems, particularly those associated with increases in temperature and water stress. It is emphasized that the genetic improvement of plants, based on the experience in the past, has much to contribute to mitigate these problems. To invest in the breeding of new cultivars, selected under stress conditions, is certainly the best possible strategy for agriculture to cope with changes caused by climate alterations.*

**Key words:** stress tolerance, plant selection, plant genetics, plant breeding.

The discussion on the consequences of climate change is spreading across the world and to different knowledge areas. Estimates of changes in the global temperature are still uncertain (IPCC 2007). Nevertheless, however low they may be, the consequences will be felt by all humanity to a greater or lesser degree. The most relevant fact is that most of the effects of these changes will affect developing countries (Lobell 2008).

In the case of agriculture, the estimates are alarming because of the difficulties, particularly of feeding the entire population of the planet. This fact has led some economists to predict food shortages in the twenty-first century. There are reports that in some regions of the planet, above all in Africa, the ability to feed the population will be greatly reduced (Lobell 2008). In the case of Brazil, forecasts predict that it will no longer be possible to grow coffee in most of the state of Minas Gerais, the largest Brazilian coffee producer (CONAB 2008). In this scenario the consequences will be catastrophic, not only for farmers, but for the

economy of the entire state as well.

Numerous research efforts in all knowledge areas are being implemented to mitigate as much of the predicted problems as possible. The genetic improvement of plants, based on experiences of the past, is an area that can make contributions to the adaptation of plants to the new agricultural scenario of the coming years. This article discusses what happened in the past and how in the coming decades improvement will play a decisive role in food and energy production.

### **Genetic progress in cultivated species: from domestication to the twentieth century**

The process of plant domestication began ten thousand years ago and occurred simultaneously in different parts of the world (Allard 1999). This seems to be a long period, but compared to the origin of the universe, which allegedly occurred more than ten billion years ago, this is a rather short time. If the origin of the universe were projected into a period of 24 hours,

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agriculture would appear only in the last minute of the day. Comments on how the domestication process may have occurred were presented by Allard (1999) and Gepts (2004), among others. In summary, domestication occurred in at least eight ecological regions and resulted in the domestication of approximately 3,000 species. Today however, only 15 species account for almost all carbohydrate and protein sources consumed by humans (Allard 1999).

In principle, domestication is the first stage of selection and was the beginning of agriculture. However, man continues to perform selection until the present. In this sense, domestication is an ongoing process (Gepts 2004). The advent of the science of plant and animal breeding after the discovery of the genetic principles has accelerated the process and paved the way, as it will be shown below, that in terms of yield the performance of crops in regions other than where they were domesticated is generally considerably higher.

Corn, for example, is native to Mexico. Based on the ear length it is estimated that corn yield was 0.5 to 0.6 t ha<sup>-1</sup> around two thousand years ago. According to Gepts (2004), this fact shows that the success with selection in the period prior to these 2000 years was fast, mainly because selection involved major genes that affect the architecture of the inflorescence. There is evidence that, soon after the discovery of America, corn was brought to Europe. For about one century almost no maize was grown, due to religious reasons. From the seventeenth century on, cultivation began in France. The agronomic performance of corn eased the hunger that was a characteristic feature of the seventeenth and eighteenth centuries (Duvick 1996).

In the late nineteenth century corn returned to the U.S. of America by English settlers. In this period, already somewhat improved, the average yield was over 1.4 t ha<sup>-1</sup>. Yields remained at this level until around 1930, when the cultivation of hybrid maize began. It is worth remembering that only double hybrids had been grown until then. This type of hybrid maize remained in use until around 1960. From then on the U.S. market for corn began to use the simple hybrid. The grain yield of the harvest in 2008 was almost seven times as high as in 1930. This spectacular increase was due to the enhancement of management systems, especially the intensification of nitrogen application, weed control, increase in plant populations per area and a frequent replacement of the commercial hybrids (Russell 1991,

Troyer 2004, Duvick and Cassman 1999, Cardwell 1982). However, it is estimated that at least 50% of this increase was due to genetic improvement (Cardwell 1982).

Some studies have been conducted to assess what changes occurred in the hybrids as a result of the work of breeders (Tollenaar and Wu 1999, Tollenaar 1991). Troyer (2004) comments that the breeders' greatest merit was the adaptation of a plant of tropical origin to temperate conditions. Underlying this success was the selection of plants or progenies adapted to long days, tolerance to lowest minimum temperature, tolerance to drought and a shorter vegetative and reproductive period than in the region of origin. Duvick et al. (2004) comments that the increased yield of the most modern corn hybrids was not a result of an increase in yield potential per plant. It was due to the ability of hybrids to produce a minimum quantity of grain, about 0.15 kg per plant, when grown at high densities. Tollenaar and Wu (1999) also discussed several changes in the physiological and agronomic performance of corn plants due to improvement. They emphasize that the success was due to increased stress tolerance.

In summary, corn originated in Mexico, 18° northern latitude, is now grown from 58° northern to 40° southern latitude. It is grown from the sea level, 0 m, up to an altitude of 3808 m asl, in other words, on virtually the entire planet (Miles and Pandey 2004), in most cases exceeding the performance of the region of origin. By the natural and especially by artificial selection plants were adapted to the most different ecological niches. The same fact is observed for almost all other cultivated species (Miles and Pandey 2004, Tracy et al. 2004). The success of breeding in the past allows the inference that the same may occur in the future, to face the possible climate changes that are bound to occur.

#### **Losses in genetic potential for yield under stress conditions**

Most plants, in almost all situations, are grown in unfavorable environments for their growth and development. That is, they usually undergo some kind of stress. As a result, they are prevented from expressing their full genetic potential for grain yield, fiber, and fruits and are considered stressed. These stresses can occur for several reasons: lack or excess of water and nutrients, high or low temperature, occurrence of different pathogens and pests, weed incidences, and many other

factors. The yield potential of a plant is fully expressed when it is grown in the environment to which it is adapted, without nutrient and water limitations and with an effective control of pests, diseases, weeds, lodging, and of other factors (Evans 1993).

There is little evidence that the genetic potential of major crops was altered through genetic improvement in recent decades. Advances resulted in an increased tolerance to abiotic and biotic stresses, as shown for corn (Duvick and Cassaman 1999, Duvick et al. 2004). Ort and Long (2003) estimated that on average, the reduction in yield potential due to stress exceeded 75%. Of this total, only 11.6% was associated with biotic stresses such as pests, diseases and weeds and the remaining 66.9% with abiotic stresses. Of the abiotic factors, drought is by far the major contributor to crop failure in temperate climate.

The results of the stress effects on yield are more significant in tropical and subtropical conditions. Paterniani (2000) compared cultivation in the tropics to temperate conditions. He showed that in tropical conditions stresses are much more intense and the challenges to increase yields greater. Nevertheless, above all in the last 40 years, cultivars obtained in Brazil contributed decisively to the increase in grain yield and other products (Vencovsky and Ramalho 2005). This increase was mostly due to the breeding of cultivars more tolerant to biotic and abiotic stresses.

### Plant genetic improvement to mitigate heat and drought stresses

The climate changes are expected to intensify the damage caused by both biotic and abiotic stresses. However, the effects of abiotic stresses are expected to be greater, mainly temperature increases and rainfall decrease in some regions, or of drought stress (Bates et al. 2008). These two stresses - heat and drought - will need most attention. An extensive review about heat tolerance in plants was presented by Wahid et al. (2007). The strongest focus was to identify tolerance genes and assess the contribution of molecular genetics. These authors concluded that the advances were small. In fact, temperature tolerance is a complex function, difficult to be measured, since it depends on the temperature grade and exposure period.

Normally the threshold temperature, or the value thereof from which the reduction in plant growth begins to be visible, of some important species is broad and varies with the stage of development of the plant (Table 1).

Extreme temperatures cause severe injuries, including cell death within minutes. However, even exposure to temperatures that are not extremely high, but persist for a longer period may also cause irreversible damage, leading to plant death. Possible damages are protein denaturation and increase in the lipid membrane fluidity. Even enzyme denaturation may occur in chloroplasts and mitochondria and blocking of protein synthesis. Wahid et al. (2007), report several other changes that affect plant performance, especially during or after flowering.

There is evidence that the most significant damage is not caused specifically by the high daytime temperatures, but rather by the amplitude of variation between day and night temperatures (Steiner and Hatfield 2008). This is also one of the most important aspects of global warming. A reduction in this amplitude is expected.

There is not much information in the literature on specific research results concerning increased tolerance to high temperatures. However, in Brazil, there are some reports of great success for heat tolerance. One of the most significant was the adaptation of cauliflower cultivars to Brazilian conditions. Marcilio Dias, lecturer at the ESALQ in the 1960s, achieved, by selection, cauliflower cultivars, which previously grew only at low temperatures in mountainous regions of Brazil, that are tolerant to high temperatures and can be grown across almost the entire country (Ikuta 1969). The same success was obtained with other brassica. In the case of carrot, similarly, a population was introduced from Europe to coastal regions of Rio Grande do Sul. Marcilio Dias selected heat-tolerant plants, enabling seeding in the Brazilian summer. Currently, carrot is grown nearly all over Brazil.

In Europe, the United States and Argentina, which are fruit-producing regions in temperate climate, over

**Table 1.** Threshold temperature for some cultivated plant species

| Species      | Threshold temperature °C | Growth stage   |
|--------------|--------------------------|----------------|
| Wheat        | 26                       | Post- anthesis |
| Maize        | 38                       | Grain filling  |
| Cotton       | 45                       | Reproduction   |
| Pearl millet | 35                       | Emergence      |
| Tomato       | 30                       | Flowering      |
| Brassica     | 29                       | Flowering      |
| Grass        | 41                       | Flowering      |
| Rice         | 34                       | Grain filling  |

Adapted from Wahid et al. (2007)

800 hours of cold (below 7 °C) are recorded. In most regions however where these fruits are grown in Brazil, even at the highest altitudes, less than 200 hours of cold are recorded. Therefore, less cold-demanding clones had to be selected (Ojima et al. 1993, Denardi and Camilo 1998). Currently, Brazil produces fruits of practically all species of the temperate climate and even exports them. These facts show that the adaptation of plants from temperate climate to tropical conditions was due both to the action of natural as of artificial selection for increased heat tolerance.

As already mentioned, drought is stress number one for crops grown around the world. It is estimated, for example, that in Africa drought causes the loss of about 300 tons of common bean annually. It is further estimated that worldwide 60% of the area growing common bean is affected by drought stress (Beebe et al. 2008). In Brazil, the damage caused by drought stress is significant. In the South, for example, over 25% of the soybean harvest in the 2003/2004 and 2004/2005 growing seasons was lost (Nepomuceno et al. 2006). Losses of similar magnitude can be extrapolated to other species and conditions of the country. It can be said that drought affects the entire agribusiness which in turn affects the entire population.

There are some alternatives to reduce the damage of drought-stress. One is the rational use of irrigation water. Approximately 70% of the drinking water of the world is used for irrigation (Somerville and Briscoe 2001). It is easy to imagine that the use of this scarce resource will be increasingly questioned. It is therefore necessary to increase the water use efficiency (WUE) of plants. This concept was established in the beginning of the twentieth century and is defined as the proportion of biomass produced in relation to the quantity of water consumed (Steiner and Hatfield 2008). All efforts should be directed towards improving the water use efficiency.

Another alternative to reduce the damage of water stress is through the development of more drought-tolerant plants. This is perhaps the issue that has raised most interest on the part of researchers in agricultural sciences. There was progress, albeit small, in response to the direct investments to solve the problem. Cecarrel et al. (2006) pointed out some reasons for this partial success: i) the difficulty to identify the critical water level, which varies among plant species, location and development stage, ii) the difficulty of identifying the ideal environment and time to begin stress simulation,

iii) which traits should be considered to verify tolerance.

Some examples of selection performed in specific traits were related by Cecarrel et al. (2006). So far there is no consensus in this regard. At least apparently, the yield of the commercial product is the most important since it is an index that reflects the performance of all others.

The use of molecular biology to mitigate drought-related damage has been intensified in recent years. However, no solution to the problem has been found yet. It is known that the number of genes involved in the process is great. Several research groups, including Brazilian scientists, are working hard on drought resistance induced by Dehydration Responsive Element Binding (DREB) Protein, for example. It has already been demonstrated that these proteins regulate the expression of genes involved in various defense responses against cellular desiccation (Nepomuceno et al. 2006). It is therefore expected that desiccation tolerance can be increased by breeding transgenic plants that overexpress DREB proteins. According to Cecarrel et al. (2006) significant resistance to water stress was observed in transgenic greenhouse wheat plants expressing the gene DREB 1 A, compared with the control. However, under field conditions, the yield of the transgenic was lower than of the control plants.

Cecarrel et al. (2006) revised the findings of the 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production under Drought Stress, in Rome, Italy, in 2005, emphasizing that: “despite the significant increase in genomic information, the application rate of this information to solve the farmers’ drought-related problems was proportionately minimal. It was found that the contribution of marker-assisted selection (MAS) in the identification of drought-tolerant plants did not meet the expectations. In summary, the available results showed a chance of success with the techniques of molecular biology to mitigate drought problems, though the way there is long.”

#### **An outlook on breeders’ work in the coming decades**

The future is always uncertain, but it is what we will live in. In the scenario of climate change, these uncertainties are even greater. Despite all technological advances, models of climate forecasts in the medium and long term will still need to be corroborated. Evidence indicates however that the CO<sub>2</sub> concentration in the Earth’s atmosphere tends to increase

continuously, as it occurred in the twentieth century (Koski 1996). The same is expected with temperature. It is however not known, how much the impact will increase and the effect it will cause on the planet and the living creatures on it.

What should be done to mitigate the effects of global warming? There are several areas of knowledge that can and must make a contribution. In terms of cultivated plants, genetic breeding should have a significant participation. In the context of improvement, all available technologies will be important. The comments of Dias and Lopes (2007), about the tools that should be used to obtain plants more tolerant to the stresses caused by global warming, do not make sense. These authors state that “it is possible that the speed of global change may antiquate conventional methods of agricultural innovation such as breeding and chemical pest control, which among others have been the main instruments of adaptation of organisms used in agriculture so far.” This statement lacks a scientific basis as laid out above in this paper. The experience of the past and more recent events are evidence that the predictions of these scientists will certainly not come true.

The example of soybean in Brazil is a clear sign that improvement can and should not be underestimated. In only four decades (1960-2000), soybean production in Brazil increased 12-fold (EMBRAPA Soja 2004). It is important to emphasize that this growth was due to the increase in yield, rather than an increase of the cultivated area. Above all, it caused profound changes in the country. With the expansion of soybean the agricultural borders in Brazil were extended, the agribusiness became more international and particularly the expansion of the agro-industry of soybean meal resulted in an increase of the domestic poultry and swine. To make this possible, cultivars had to be bred with a long juvenile period and tolerant to the temperature and soil conditions in the Cerrado of central-western Brazil (Vencovsky and Ramalho 2006). Besides, strains of atmospheric nitrogen-fixing *Rhizobium* adapted to soils under Cerrado were selected. In turn, soybean plants whose association with these new *Rhizobium* strains had been improved were also selected. Thanks to these selections, nitrogen is no longer used in soybean in Brazil and the reduction in the production costs is remarkable. Additionally, the environmental impact of soybean cultivation has also been reduced. This is a

clear proof that selection performed by breeders will never become obsolete.

By the way, Egli (2008) concluded, after reviewing the historical yields of maize – a C4 grass with high photosynthetic efficiency - and of soybean – a C3 legume with moderate efficiency - in environments in the United States with low and high technology, that the annual yield growth rate was similar (1.8% for corn and 1.4% for soybean), with a slight advantage for low-technology environments. If such efforts obtained results in the past there is no reason to believe they could not be repeated in the future.

Experience has shown that biotic and abiotic stresses occur together, although not necessarily all at once. Normally, when temperatures are elevated, for example, water stress on plants is strong and pest incidence, among other stresses, increases. To identify more tolerant cultivars to all these factors the available alternative, with proven efficiency, is to evaluate the progeny and/or cultivars in the conditions in which the crops will be grown.

In this context, the main drawback to the work of breeders is the interaction of genotypes with environments. In other words, genotypes respond differently to environmental stimuli. Therefore, especially under tropical conditions, where the diversity of climate and management adopted by farmers is higher, the interaction of genotype by environment is the greatest challenge to be met. Cultivars must be well-adapted and more stable.

For this purpose, the only possibility is to evaluate progenies and/or cultivars in a larger number of possible environments. This is the most difficult and costly phase of cultivar breeding. Even in temperate conditions, with less climatic diversity, the investment of large seed companies in the evaluation of commercial hybrids, for example, is enormous (Duvick and Cassman 1999, Troyer 1996). However, any technique to be used to obtain more stress-tolerant plants, such as e.g., transgenic plants, the above-mentioned stage of evaluation in field conditions cannot be avoided (Goodman 2004).

The information available points to an increasing demand for breeders with a sound theoretical basis. This theoretical basis involves knowledge of molecular biology of plant science and mainly of basic and quantitative genetics. Moreover, these professionals must be qualified to conduct and interpret field

experiments as efficiently as possible. Although there are to date no conclusive data, the number of professionals available with this qualification is insufficient to meet even the current demand. For the new scenario of climate change this kind of specialist is of utmost importance and there is no prospect that the number will increase, if nothing is done to reverse the trend.

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# Melhoramento genético de plantas e mudanças climáticas

**RESUMO** - *As conseqüências das mudanças climáticas para o agronegócio brasileiro tem sido amplamente debatida. Nessa publicação esse tema é abordado mostrando os problemas que são esperados especialmente associados ao aumento na temperatura e a deficiência hídrica. É enfatizado que o melhoramento genético das plantas, fundamentado em experiência do passado, tem muito a contribuir para mitigar esses problemas. O investimento na obtenção de novas cultivares, selecionadas nas condições de estresse, certamente é a melhor estratégia para a agricultura enfrentar as alterações devido as mudanças climáticas.*

**Palavras-chave:** tolerância a estresses, seleção de plantas, genética vegetal, melhoramento de plantas.

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