Collection, conservation, improvement, and recommendations on using genetic resources aiming at climate change

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Climate change is characterized on a global scale as an increase in the concentration of atmospheric CO_2, an increase in temperature and a greater occurrence of extreme rain events, affecting the availability of water in the soil. These factors and their interactions affect the growth and development of plants and, consequently, the productivity of agricultural crops and livestock.

Currently, the world's population food supply is based on a small number of cultivated species, such as rice, corn, potatoes, and wheat. This dependence on few types of crops and the narrow genetic basis of each crop released into the market are factors that make the whole agri-food system vulnerable. If biotic or abiotic stress occur, it may result in a significant drop in production. This is not unprecedented in history. One example is the great famine from 1846 to 1849 in Ireland, when approximately 25% of the population died of hunger due to a potato plague caused by a fungus called Phytophtora infestans, which practically decimated the entire crop of that country. The same is true for abiotic stress factors, as shown in climate change studies. The consequences can be drastic if no new genetic materials are adapted to these conditions. Crop diversification protects the entire production system and its consumers, enriches the quality of the human diet and recognizes food culture associated with the traditions of countries and peoples.

In order to successfully launch new crops into the market, studies focusing on the evaluation of genetic resources for the adaptation of agricultural production systems to climate change need to take into account the following lines of research: collection, introduction and conservation of germplasm; domestication of species; characterization and evaluation of genotypes, biotechnology, genetic improvement and development of new crops; and recommendations for new crop use and management practices. In addition, producers must have access to new material and technical recommendations for proper cultivation.

Expanding the genetic basis for the characteristics of interest in the germplasm collections is the first step to guarantee success in selecting desired genotypes. There are different ways to expand this genetic base: germplasm collection in areas where the plants are already adapted to climatic stress conditions, whether they are wild species related to the cultivated species targeted by the breeding program or varieties grown by local farmers and introduction of genetic material from other national or international sets, be they characterized or not. Therefore, the maintenance of genotypes in institutional germplasm banks is essential to ensure that genetic materials of real or potential value can be properly preserved for their immediate or future use. The collection and introduction of materials adapted to abiotic stresses and their efficient conservation and documentation is essential to provide breeding programs with exotic alleles to those already found in the breeders' collections.

This also ensures that these materials are not extinguished by situations such as the emergence of new cities or plantations in the locations of native plant populations.

Plants adapted to swampy places such as the Pantanal may have developed structures such as aerenchymas that allow for more efficient gas exchange. Short-cycle plants found in places with a very short wet season may have very fast and efficient growth and fruiting mechanisms to quickly complete their vegetative cycle. Locations with low levels of rainfall can shelter plants adapted with a deep root system to reach a large area of soil and, consequently, a greater chance of capturing water, or with small leaves and thorns that reduce transpiration. These characteristics are composed of a set of interesting alleles that should be part of the breeder's collection. When this material is collected, it can be tested in different environmental conditions, crossed with more productive and promising materials and the best progenies can be selected as more adapted to the climatic conditions in which they were tested.

The domestication of new species can contribute to diversify people's diets. Species still considered wild often provide interesting characteristics to the human diet, such as high content of amino acids or antioxidants. However, cultivating the plants the way they are today does not guarantee commercial scale, either because of productivity or the extensive vegetative time until harvest. Domesticating species can contribute to the expansion of crops and their use in human consumption.

Research associated with preventive improvement, that evaluates genotypes against a certain stress before it reaches the country, are fundamental to safeguard Brazilian production from major climate changes. There are preventive improvement studies with very successful results in Brazil, such as those associated with quarantine pests. One of the main examples of preventive improvement was Dr. Alcides Carvalho and the Instituto Agronômico team's development of coffee plants that are rust-resistant. When the rust arrived in Brazil in 1970, the team already had material resistant to it, considering the research had started in 1953. Preventive improvement programs are needed to preempt abiotic stresses such as those that will be observed in extreme cases and associated with climate change.

The assessment and identification of new genotypes that are more adapted to climate change depend on studies of various scales and may involve only one climate variable or several of them and their interactions. Studies in closed growth chambers (phytotron) allow more precise control of temperature, CO2, luminosity, photoperiod and water availability, conditions which are quite different from the natural environment. In greenhouses or in the countryside, there is the possibility of partially controlling the environment using irrigation systems, open top chambers, FACEs (Free-Air CO2Enrichment) or T-FACEs (Temperature-Free-Air CO_2Enrichment), which allow the combination of the effect of water availability, temperature and CO_2 enrichment. Equipment with CO2 injection in an open environment has a very high maintenance cost, which often makes its use unfeasible. Another option is carrying out experiments in places with a climate similar to that projected by the climate change scenarios for the area of interest.

One of the challenges of research in a modified environment is the definition of the climatic scenarios used in the experimentation. Generally, climate change treatments are based on global projections and variations above or below the current value. There is a need to improve regional climate scenarios and define scenarios with respect to extreme events.

To circumvent the experimental difficulties related to the study of climate change scenarios, research groups have studied, based on simulations with mathematical models, the effect of scenarios and alternatives for adaptation. To ensure this, international partnerships have been established with universities and a research center that develop simulation platforms, such as DSSAT (Decision Support System for Agrotechnology Transfer) and APSIM (Agricultural Production Systems Simulator), among others. Using these platforms requires primary data on growth and production of agricultural crops and pastures for their parameterization, which is not always available. Based on the parameterization of the models, scenarios are analyzed in terms of the vulnerability of genetic materials and of production systems.

Another major bottleneck for the identification of plant genetic resources adapted to climate change and its application in plant breeding programs is large-scale phenotyping, especially in a short period of time and with low labor demand. The development of this type of phenotyping methodology requires high investments in technologies and training qualified personnel. These methodologies are based on sensors and high-resolution cameras that detect different types of images in different plant tissues and scales and develop platforms for data collection and methodologies for processing and analyzing that data, including the development of algorithms, models, and software. The methodologies can be applied at different scales, from tissue-specific or remote sensing and geotechnologies with using unmanned flying vehicles (drones) and satellites. Each type of morphophysiological characteristic and tissue/morphology of the crops/species of interest requires a specific methodology, which signals great opportunity for methodological development. Besides this, existing literature has not reached a conceptual consensus regarding the characterization of what exactly would be resistance, tolerance, adaptation, resilience, and survival to abiotic stress factors. This is the main reason why it is difficult to establish appropriate methodologies.

Biotechnological tools can also be applied to identify genomic regions related to climate change tolerance (drought, waterlogging, increase in atmospheric $CO2$ concentration, among other stresses) and the development of plants adapted to these conditions. Genes and regulatory regions of the genome that provide greater tolerance have been sought using approaches such as transcriptome analysis and genomic selection under controlled stress conditions, both in cultivars of interest and in selected genetic resources based on their natural adaptation to the desired trait. Gene editing systems such as genetic transformation and, more recently, CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) have been used to incorporate specific genes that act on metabolic pathways that confer greater capacity for plants to tolerate and/or resist these stresses, such as the abscisic acid pathway in the case of drought tolerance. Such approaches are applied directly to elite germplasm or cultivars that are already developed and do not have the desired characteristic.

After obtaining promising material for the desired conditions, new cultivar must be evaluated in conditions close to final use conditions to define recommendations and appropriate management practices. Ideally, these studies should be carried out in large areas, in places likely to establish various biotic and abiotic interactions that can influence the performance of the material. We know that interactions between plants, animals and microorganisms are very important and often fundamental for certain crops to adapt in some regions. Many microorganisms have already been identified as plant growth promotors, such as nitrogen-fixing bacteria, phosphate solubilizers, and indole-acetic acid producers, most of which can already be found on a commercial scale. There are microorganisms that acidify the soil and others that produce compounds that kill other pathogenic microorganisms. Research on the interaction of plants and microorganisms that evaluates plant growth under conditions of abiotic stress is also of fundamental importance, as it substantially reduces time spent in obtaining new adapted cultivars.

In Brazil, there are several research groups working on adapting agriculture and livestock to climate change (Examples: figures 1 and 2). Most of the work focuses on generating knowledge, given the need to expand the development of technologies and create mechanisms to boost adoption in the most vulnerable regions.

Figure 1: Embrapa demonstration field with forages.

Crédit: Juliana Sussai.

Figure 2: Embrapa demonstration field with forages

Crédit: Juliana Sussai.

This compilation is a small sample of the research focused on genetic resources aimed at adapting Brazilian agricultural systems to climate change. 16 of the studies submitted were directly related to the topic "genetic resources" (pages 32 to 63); another 16 studies were indirectly related to the theme and were inserted in chapters 2 (pages 78, 90 and 100), 3 (pages 112, 114, 116, 118, 120, 126 and 130) and 4 (pages 144, 146, 148, 152, 156 and 158).

The research gathered in Chapter 1 includes the following classes of crops: temporary crops (melon, beans, rice, cowpea, soy, corn, and sugar cane) and permanent crops (grapes and coffee), horticulture (onions and potatoes), livestock (natural and planted pastures) and forest production (eucalyptus). A cattle evaluation project was also included. In the other chapters, research related to genetic resources focused mainly on the study of natural species (natural pastures of the Caatinga and Pantanal biomes, natural fruits of the Cerrado and Caatinga, araucaria, butiá etc.) and focused on zoning, the development of biodiverse production systems, the diversification of people's diets and the domestication of natural species.

Among the research directly related to the topic "genetic resources", most focuses on the regions of Central Brazil and the Semi-Arid region and involves solutions for adapting agriculture in the Caatinga, Cerrado, Atlantic Forest and Amazon biomes. Drought is the main climatic factor addressed, but there are also studies considering variations in temperature, CO2 concentration, irradiance, extreme flooding and droughts, salt stress and interactions between more than one of these factors.

The research presents different gauges of experimentation, from plant or animal level to ecosystem and landscape level. The tests at plant or animal level focus mainly on genetic, biochemical, metabolic, or physiological responses of plants/animals to climate factors and are mostly carried out in controlled environments (phytotron chambers or greenhouses) or in small plots. Biotechnological approaches have been applied to identify genes and develop cultivars adapted to climate change. Biotic interactions between plants/animals and microorganisms are also investigated. In the case of plants, studies focused on the relationship with pathogenic microorganisms. In the case of animals, studies focused on the relations with rumen microorganisms, which affect the feed efficiency and animal ability to adapt to the environment.

The trials at the plant community level are aimed at eco-physiological, production or disease occurrence assessments and are usually carried out in small plots. Open top chambers, FACEs, T-FACEs, irrigation systems and other mechanisms are used to cause changes in the plot's microclimate. Resource production and efficiency and the occurrence of diseases are the main aspects evaluated.

Studies on larger scales contemplate production systems, regions, or ecosystems. They are usually carried out in large plots, in some cases permanent, and focus mainly on production, product quality and resource efficiency. Studies on larger scales work to validate technologies for posterior transfer to the productive sector.

The main results in this compilation are related to the advancement of knowledge, the development of technological and pre-technological assets and the recommendation of agricultural practices or processes. The knowledge generated relates to plants and animals' mechanisms of response to climate factors and their interactions with microorganisms. Pre-technological assets correspond to genes and molecular markers related to responses to stress, which can assist in the selection and development of new cultivars. Technological assets correspond to the development of new cultivars, via genetic improvement, selection and/or genetic modification. Agricultural practices or processes are mainly related to the recommendation of genetic material for specific conditions, combinations of plants for intercropped cultivation or in crop-livestock-forest (ICLF) and agroforestry (SAFs) integration systems, plant management practices, irrigation management practices and preventive or curative disease control practices.

The sample of studies gathered in this compilation suggest that there is no homogeneity between the methodological approaches, which was expected due to the great variety of species and environmental conditions. On the other hand, the definition of several concepts and indicators would contribute to swifter advances in adapting Brazilian agriculture to climate change.

In Brazil, there are research groups investigating strategies for adapting agriculture and livestock to climate change using genetic resources, but further progress is needed to increase the resilience of production systems and ensure the sustainability of national agricultural and livestock production in the future. Despite the existing competences and capacity for research in the country, the volume of results is still small compared to the size of national agriculture and livestock production. The actions of different institutions are not well orchestrated, which often makes it difficult to develop a solution ready for adoption by the productive sector. In addition, the possibility of validating results at the scale of a production system for long-term scenarios is limited.

The following actions can contribute to increasing the country's capacity to adapt to climate change:

- Encourage innovation: strengthen public science and technological institutions and establish mechanisms that facilitate interaction between public and private institutions;

- Collection, introduction and conservation of germplasm: support the actions of public institutions responsible for the collection, introduction and conservation of germplasm in the country;

- Domestication of new species: identify wild species with the potential to reduce the country's vulnerability to climate change and support domestication actions;

- Preventive genetic improvement: identify, through scenario studies, the priority crops for preventive improvement actions; encourage the development of large-scale phenotyping methods to identify promising accesses from the point of view of adaptation to climate change; encourage the establishment of research networks focused on the development of new cultivars through traditional genetic improvement and molecular genetics techniques;

- Recommendations for use: encourage the establishment of research and development networks associated with preventive genetic improvement networks that evaluate materials on a large scale and determine recommendations for their use in each region; and

- Technology transfers: facilitate and encourage the establishment of public-private partnerships for the multiplication and commercialization of seeds from adapted cultivars, especially in the most vulnerable regions; promote the establishment of technical assistance and rural extension networks that promote the adequate use of new technologies by producers, especially in the most vulnerable regions.

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