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Embrapa's contribution to the development of new plant varieties and their impact on Brazilian agriculture

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Abstract – *Plant breeding programs conducted by Embrapa and partners have significantly contributed to major qualitative and quantitative advances achieved by the Brazilian agriculture over the last 40 years. In this article, an overview of the diversity of crop species and the multiple goals established by Embrapa's plant breeding programs is presented, highlighting some of the main contributions to the agricultural sector. The economic, social, and environmental impacts of the major cultivars released by Embrapa are reviewed and an analysis of the present and future role of the institution in cultivar improvement for tropical and subtropical regions is provided. Risks, opportunities and challenges of this endeavor are discussed, considering the recent market changes and innovations observed in the seed industry in Brazil.*

Key words: *Plant breeding, technological innovations, seed market, cultivars.*

INTRODUCTION

The Brazilian Agricultural Research Corporation (Embrapa) and its partner institutions have played a central role in the development and expansion of Brazilian agriculture in the last 40 years (Silva and Albuquerque, 2008). During this period, Embrapa has become one of the leading institutions for science and technology (S & T) in agriculture for the tropical region, consolidating its reputation of research excellence with scientific communities, farmers, consumers, industry sector, and general public in Brazil and abroad (Alves 2010). Embrapa is a network of 47 research units located in almost all states of Brazil. Its innovative institutional model includes research centers for strategic themes, specialized products and eco-geographical regions. The specialized product units are devoted to research and innovation for the most important crop species used in the Brazilian agriculture, including corn, wheat, rice, beans, soybeans, cotton, vegetables, etc. The units dedicated to strategic themes are responsible for developing and adapting knowledge, processes and innovations in biotechnology, genetic resources, advanced instrumentation, information

technology, among others. The mission of the eco-regional units is to adapt innovations, technologies, information, and production systems that enable the sustainable use of natural resources of the different Brazilian biomes (Lopes 2011).

Plant breeding has been, since the foundation of Embrapa, one of its most important activities, with results that have contributed significantly to the main qualitative and quantitative gains achieved by Brazilian agriculture over the past decades. In its early days, Embrapa invested vigorously in genetic resources, searching for germplasm suitable for tropical and subtropical conditions, both through the collection of native plant species, as through the enrichment of its exotic germplasm collections with plant accessions from other countries. A cooperation network was established with the international centers of the Consultative Group on International Agricultural Research (CGIAR), with the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA), with the Agricultural Research for Development (CIRAD) in France and with universities and national organizations from multiple countries. This network has enabled the rapid introduction of

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germplasm for pre-breeding programs, which mobilized genetic variability for multiple public and private breeding programs operating within the country. In the following years, Embrapa and partner institutions provided significant contribution to the adaptation of large number of crops that became important pillars for the development of Brazilian agriculture. The diversity of breeding programs has been one of the landmarks of Embrapa's contribution to the development of Brazilian agriculture over the past four decades.

The present review discusses plant genetic improvement as one of the central topics for research and development, and technology transfer since Embrapa's creation, highlighting the contribution of the corporation for the development of the cultivar market and for structuring the seed industry in Brazil. It also highlights the present and future role of Embrapa's innovations in this market, discussing risks, opportunities, and challenges ahead, considering the changes observed in recent years and those that might be anticipated for the future.

GENETIC RESOURCES: THE BASIS OF THE PLANT BREEDING PROGRAMS

The strategic importance of plant, animal and microbial genetic resources for the Brazilian agriculture was recognized by Embrapa since its creation. Embrapa's teams have dedicated substantial efforts and resources to the establishment and maintenance of a national network of genetic resources. This network has a multi-institutional dimension, whose leadership and administration was taken by Embrapa, considering the importance of this research area for the whole Brazilian agricultural research community. This was an strategic decision, which allowed the consolidation of Embrapa as a public agricultural research organization. This work continues to be crucial to Embrapa's current programs and to the future of the Brazilian agriculture.

The network of plant genetic resources coordinates the activities of collection, exchange, quarantine, conservation, characterization, evaluation, documentation and use of plant genetic resources in Brazil. Similar activities are also developed for genetic resources of animals and microorganisms. A significant collection of plant accessions, composed by a large number of varieties, clones and populations of plant species used in agriculture, is preserved in gene banks distributed throughout the country.

Germplasm has been used in the development of varieties, cultivars, hybrids, clones and populations of several plant species. They have been made available to the market in the last four decades, providing great contributions to the Brazilian agriculture and the agricultural development of

the tropical region (Queiroz and Lopes 2007). It should be emphasized that this is an effort that benefits both, public and private sectors, since plant genetic resources are supplied to breeding programs of all research institutions in the country. Genetic resources research are, therefore, one of the most important tasks of Embrapa, with direct impact on Brazilian agricultural research.. The conservation and use of genetic resources should be at the core of the debate about food security and agricultural sustainability in Brazil. This is an issue that directly affects national security and, as such, recognized in many countries worldwide.

Embrapa and partner institutions are responsible for the conservation of approximately 300,000 accessions in Germplasm Banks of distinct plant species distributed throughout the Brazilian territory (Figure 1). These collections represent a genuine contribution to the conservation of plant genetic resources worldwide due to their diversity of species, including native species of different biomes, in addition to traditional varieties adapted to different regions of the country. In association with each Germplasm Bank there is a breeding program, or coordinated actions with direct users of the plant germplasm kept in the collections. In addition, Embrapa maintains germplasm collections of other plant species, which may eventually assume the status of Germplasm Bank in the future, once associated with breeding programs. Embrapa also maintains a Base Collection of plant genetic resources, which represents a safeguard for future generations. In the Base Collection, seeds of 120,000 accessions from 700 plant species are maintained at low temperature and controlled humidity. The Base Collection has great strategic value, since it maintains germplasm that are representative of the genetic diversity of the main species of Brazilian agriculture in conditions that allow for the preservation of their viability for many years, for the use of future generations. Embrapa also has collections of plant pathogens and beneficial/symbiotic microorganisms for employment in screening programs aiming to develop plant varieties with superior traits, as disease resistance, or microorganisms of higher nitrogen fixation capacity.

Even though Brazil is one of the centers of biological mega-diversity in the world, most species that are used in national agriculture come from other countries. Exotic plant species (e.g. soybean, corn, wheat, rice, beans, sugar cane, orange, eucalyptus, vegetables, and coffee) are responsible for the major part of Brazilian agricultural GDP, representing the core of our agriculture. Thus, it is important and strategic for Brazil to have wide access to genetic diversity of these exotic species, as seeds or propagules, to allow the continuity of breeding activities. Besides maintaining collections of accessions of these species in Germplasm Banks, Embrapa









 Cereals	 Fruit species		 Vegetables and spices	 Leguminous, Oleaginous, Fibrous plants	 Industrial use	 Forest trees and palms	 Roots and tubers	 Forage species
Amaranth Barley Corn Millet Oat Rice Rye Quinoa Sorghum Triticale Wheat	Apple Avocado Bacuri Banana Barbados cherry Baru Blackberry Blueberry Brazil nut Camu-camu Cashew Cashew apple Chicha Citrus Coconut Cupucaçu Genipap Grape Guava Jaboticaba Loquat	Mamme apple Mango Murici Papaya Peach Pear Pequi Pineapple Pitaya Plum Psidium Pummelo Sapote Sapucaia Sorva Strawberry Surinam Cherry Umbu Uxi Yellow mombin	Arracacha Bell peppers Black pepper Bottle gourd Brassicas Carrot Chili peppers Cucumber Eggplant Garlic Jacatupe Lettuce Melon Okra Onion Sponge gourd Squash Pumpkin Watermelon Tomato	Castor bean Chickpea Coomon bean Cotton Cowpea Curaua Fava bean Lentil Moringa Pea Peanut Safflower Sesame Sisal Snap bean Soybean Sunflower	Cocoa Coffee Sugar cane Oil palm Mate plant Guarana Rubber tree	Acacia Acai Acrocarpus Amburana Araucaria Babassu Bacaba Caiaue Calophyllum Centrolobium Cryptomeria Cypress Eucalyptus Fiber palm Gonçalo-alves Grevillea Imbuya Mahogany Pataua palm Peach palm Pink Pepper Pinus Spiny cedar Sweet gum Tabebuia	Potato Sweet-potato Yam Taro Cassava	Alfalfa Andropogon Axonopus Brachiaria Bromus Buffelgrass Centrosema Cratylia Desmanthus Echinochloa Elephant grass Hemarthria Leucaena Mesosetum Panicum Paspalum Pennisetum Perennial peanut Ryegrass Stylosanthes

Figure 1. Germplasm Banks and collections of accessions of exotic and native species of Brazilian agriculture, maintained by Embrapa, for use in breeding programs.

has significant historical participation in the enrichment of genetic germplasm used in agriculture in the country. It happens through cooperation with international networks of agricultural research, and germplasm exchange agreements with countries holders of genetic diversity of plant species that are important to our agriculture. This is a major work, developed on behalf of the entire national agricultural sector. National and international partner institutions have been vital to the organization of these Germplasm Banks and collections, collaborating with programs of genetic diversity enhancement in the country during the past 40 years.

There are several interfaces between the conservation of genetic resources and breeding programs, with numerous examples of direct contribution to the development of new plant varieties in Brazil. It should be emphasized that the offer of genetic diversity is a major contribution of Germplasm Banks to varietal development. This is done routinely, for example, for the selection of parental accessions for development of segregating populations, or the identification of sources and introgression of genes for resistance to economically important diseases and pests, as well as abiotic stresses, into elite germplasm. However, the accessions kept

in Germplasm Banks may also be directly used by farmers as varieties, clones or populations, or as sources for pre-breeding programs. Some relevant examples of varieties released as direct contribution of Germplasm Banks with major economic, social and environmental impacts include: (1) varieties selected in provenance tests of accessions kept in Germplasm Banks (e.g. *Brachiaria brizantha* var. Marandu); (2) varieties selected in collaboration with international research institutions (e.g. Embrapa 40 wheat, in collaboration with CIMMYT – International Center for Improvement of Corn and Wheat); (3) varieties selected after purification of populations kept in Germplasm Banks (e.g. MNA 901 and MNA 902 red rice); (4) varieties derived from natural mutation of accessions kept by Germplasm Banks (e.g. Clone 30, Concord grapevine); and (5) exotic varieties selected within Germplasm Banks, which are no longer found in other countries (e.g. White Moscato grapevine).

Genetic diversity adequately preserved, accessed and used will continue to be the basic foundation for the continued success of breeding programs aimed at developing new varieties, cultivars and lines. However, Germplasm Banks also serve as a basis for the identification of new functions

and uses of genetic resources for agriculture. Some activities of Embrapa involving genetic resources that deserve attention include: (1) preventive breeding actions, especially for resistance to economically important diseases/pathogens that are not present in the country; (2) pre-breeding, aiming to expand the genetic base of current breeding programs; (3) gene mining and trait discovery for the bio-industry and for the development of new biological functions, “assets” organized in bank of traits, among other uses; (4) diversification and addition of value to genetic resources, in the form of new foods, fibers, flavors, biomaterials and new varieties with ornamental value and functional properties, and (5) increased use of genetic resources in integrated systems, such as crop-livestock or crop – livestock – forest.

The work of Embrapa in the conservation and use of genetic resources is based on the assumption that the diversity of customers implies in diverse germplasm banks and genetic improvement programs. The impact of the genetic improvement programs developed by Embrapa is a direct consequence of the organization’s success in research and development activities on plant genetic resources.

PLANT GENETIC IMPROVEMENT AT EMBRAPA: DIVERSITY OF SPECIES, OBJECTIVES AND PARTNERS

Plant breeding programs at Embrapa were established due to a combination of many factors, including market and public demands, compliance with government policies, opportunities to develop new products as well as their supply chains. There are several examples of programs that began before the creation of Embrapa, which were taken over by the organization when the original leading institutions were extinguished, as happened, for example, with the initial works with rubber tree improvement. Figure 2 illustrates the time periods corresponding to the beginning of the activities of different breeding programs developed by Embrapa.

Yield gains and regional adaptation were the initial objectives of the breeding programs at Embrapa. However, the evolution of farming systems, the establishment of new supply chains, the search for agricultural sustainability and the demands of farmers, consumers and industries, led to the improvement of other traits, such as resistance/tolerance to

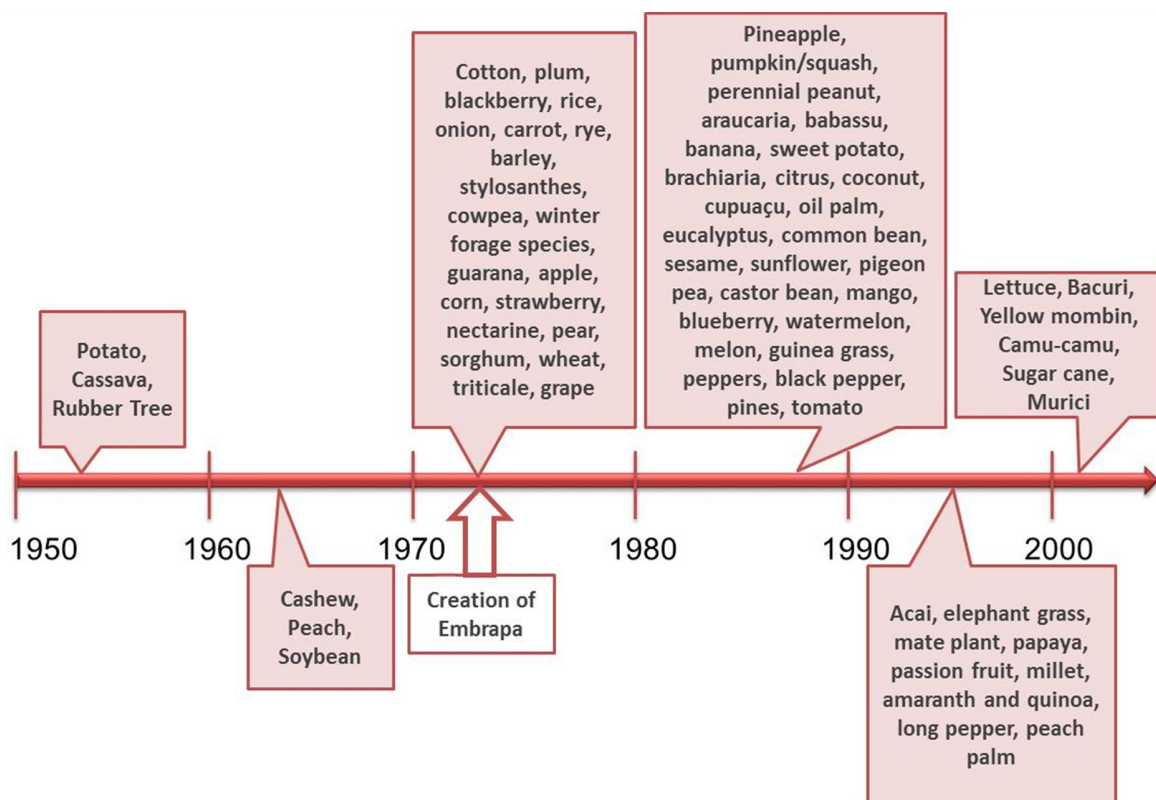


Figure 2. Period corresponding to the beginning of the activities of plant breeding programs conducted by Embrapa.

biotic and abiotic stresses, short cycle, plant size and architecture, or nutraceutical and functional properties.

Embrapa currently has 80 breeding programs in the following plant species or genera: pineapple, pumpkin, açai palm, lettuce, alfalfa, cotton, amaranth, plum, peanut, perennial peanut, blackberry, araucaria, rice, oat, ryegrass, babassu, bacuri, banana, potato, sweet potato, brachiaria, brassica, coffee, yellow mombin, cashew, camu-camu, sugar cane, elephant grass, onion, carrot, rye, barley, citrus, coconut, cupuaçu, oil palm, mate plant, eucalyptus, beans, cowpea, sesame, sunflower, pigeon pea, guarana, apple, papaya, castor bean, cassava, mango, passion fruit, watermelon, melon, millet, corn, blueberries, squash, strawberry, murici, nectarine, switch grass, paspalum, pear, peach, black pepper, long pepper, peppers (*Capsicum*), paprika, pine, peach palm, quinoa, rubber tree, sisal, soybeans, sorghum, stylosanthes, tomato, clover, wheat, triticale, and grape. Although some are in the initial phase, most of them are long-lasting programs. The great majority of the programs present successful examples of cultivar development and release to the agricultural sector. Most breeding programs led by Embrapa have also strong institutional partnership. Currently, there are over 100 research institutions that are partners of Embrapa in plant breeding programs, including universities, State Organizations of Agricultural and Livestock Research (OEPAS), national and international research institutes, and private companies (Figure 3).

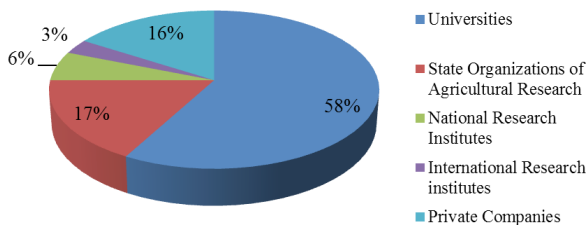


Figure 3. Public and private institutions, which have partnership agreements with Embrapa to develop breeding programs.

EXAMPLES OF CULTIVARS RELEASED BY EMBRAPA AND THEIR IMPACTS

It is an enormous challenge to review, in a complete and proper way, the entire portfolio of cultivars derived from plant breeding programs conducted by Embrapa since its creation. It is equally challenging to describe in detail the impact of all these cultivars on the development of the Brazilian agriculture. Varieties, clones, hybrids and populations from different plant species with different at-

tributes were released for cultivation in virtually all regions and environmental conditions of Brazil. This diverse range of products addressed the needs of all segments of the Brazilian agriculture, including small family-based farming communities, regional or local production sectors, and entrepreneurial, advanced agribusiness.

The contribution of breeding programs from Embrapa in the development of Brazilian agriculture can be illustrated by: (a) increase in yield and quality; (b) development of innovative partnerships to boost the productive sector and the seed and propagules markets; (c) expansion on the range of crop adaptation to different geographical regions and agroecosystems; (d) improvement of nutritional and functional attributes of foods and processing products; (e) development of new supply chains and diversification of production systems; (f) development of new products and opening of new markets; (g) consolidation of local and regional markets; (h) diversification and promotion of alternative use of species; (i) natural resources conservation and reduction of environmental impacts; (j) market development through products derived from native plant species; (k) optimization of integrated production systems; (l) reduction of production costs; and (m) delivery of new knowledge in tropical agricultural systems. In all these areas it can be found examples of impact in Brazilian agriculture caused by cultivars developed by Embrapa (Table 1).

POST-BREEDING: PROVIDING SEEDS AND PROPAGULES FOR THE PRODUCTIVE SECTOR

The consolidation of Embrapa as the main public source of genetically-improved cultivars is supported by a strong effort on post-breeding initiatives, especially in validation activities, promotion and production of basic seeds and/or propagules of the new varieties. This ensures the availability of propagation material for multiplication by the Brazilian industry of seeds and propagules, allowing the adoption by farmers. Some of the cultivars released in the 1980s and 1990s, mainly soybean, corn, rice, cotton and pastures, constituted one of the pillars for incorporation of the *Cerrado* as one of the most important productive regions of the country.

In the last two decades, due to the Plant Variety Protection Law (PVP), intense changes have occurred in the domestic market of cultivars and seeds. The possibility of obtaining royalties and returns to investment in breeding research and the outstanding development of national agriculture, stimulated the activity of several national and international seed companies in the Brazilian market. Furthermore, the

Table 1. Number of Released Cultivars (NRC) and some examples of cultivars developed by Embrapa and their respective characteristics and impacts, considering the main plant breeding programs conducted by the organization and its partner institutions

Crop Breeding Program	NRC	Exemples	Characteristics/Impacts
Rice	107	BR-IRGA 409	It represented a milestone in irrigated rice. Thirty years after its release, it is still the sixth most widely planted cultivar in Brazil. It is an example of Embrapa's collaboration with a State research institution (IRGA).
		BRS Primavera	Its excellence in grain quality contributed to add value to upland rice, reaching the same commercial value as irrigated rice.
Corn	77	BR 201	It was the first hybrid specifically developed for acid soil regions of Central Brazil. This cultivar allowed the establishment of an innovative public-private partnership (Unimilho), which resulted in the incubation of 28 national seed companies.
		BR 106	This open-pollinated variety was the most planted in Brazil for more than a decade, and the 1999/2000 season was cultivated in 400 hectares with first generation seeds. It is one of the genotypes which contributed the most to obtain new lines of dent corn adapted to Brazilian conditions.
Sorghum	24	BRS 304	For almost two decades it has been the most cultivated in Brazil. It has made sorghum an ideal alternative for a second crop conditions in Brazilian <i>Cerrado</i> .
Wheat	117	BR 18	It had a unique importance in the history of wheat production in Brazil and until today it is still grown in several regions. It presents wide adaptation, high tolerance to fungal blast, and flour of excellent industrial quality.
Barley	20	BR 2	It was a milestone in the national production of barley due to the yield increase of 400 kg ha ⁻¹ and net blotch resistance, which reduced fungicide application, production costs and negative environmental impacts.
		BRS 195	It is a high yielding dwarf cultivar. Due to its adaptation to no-tillage system, it was crucial for the recovery of cultivated areas that were damaged by the high lodging of traditional cultivars in the new system.
Triticale	13	Embrapa 53	It was important in growing areas and the first choice of farmers and millers due to its high yield and flour quality for cookies making.
		BRS Minotauro	It was the first triticale cultivar obtained by crosses and selections made in Brazil. It has wide adaptation and lower susceptibility to head blight.
Rye	2	BR 1	Even 25 years after its release, it is still grown for grain production in many production areas.
		BRS Serrano	It is a forage rye for use in ground cover and grazing. It adds value to the various cropping systems, being used to soil cover in no-tillage system and orchards.
Quinoa	1	BRS Piabiru	It is an alternative for diversification of production systems in <i>Cerrado</i> .
Amaranth	1	BRS Alegria	It is an alternative for diversification of production systems in <i>Cerrado</i> .
Peach	60	Diamante	It made possible the expansion of the harvest time from 15 days to more than three months,
Blackberry	6	Tupy	One of the most cultivated varieties in the world. It is well adapted to Brazilian conditions.
Banana	15	BRS Conquista	It is resistant to black and yellow sigatoka as well as fusarium wilt (Panama disease). It has high quality fruits and it is highly productive, being able to reach 48 tons ha ⁻¹ yr ⁻¹
Pineapple	3	BRS Vitória	Resistant to fusariosis, its leaves present thornless edges. Its fruit presents high sugar content.
Mango	5	Alfa Embrapa 142	It is a semidwarf cultivar, resistant to powdery mildew and anthracnose. It presents low incidence of fruit malformation and high yield.
Coconut	3	Praia do Forte	It is a vigorous dwarf palm, flourishing around the third year after planting. Its fruit production is superior to that of tall coconut cultivars, with high quality water and pulp.
Passion fruit	7	BRS Gigante Amarelo	They are grown in more than 450 municipalities in all states of Brazil. Its productivity is superior to 50 ton ha ⁻¹ yr ⁻¹ , and presents high physicochemical quality of fruits, ensuring greater sale value.
		BRS Estrela do Cerrado	It was the first Brazilian passion fruit hybrid for ornamental purposes.
Cupuaçu	9	Coari, Codajás, Manacapuru e Belém	They present resistance to witches' broom disease, allowing an increase of 30 to 40% on fruit production. The production costs are reduced around 10 to 20% due to the minimization of the sanitary pruning and reduction on fungicide application.
Cashew	12	BRS 275	It is an alternative for the exploitation of this crop in different ecosystems, with production of nuts with greater weight and better price in the international market.
Citrus	15	Laranja Pera seleção D-6 CNPMF	Used for <i>in natura</i> consumption and industrial processing. It is considered the foundation of the citrus industry in the North and Northeast Brazil, presenting high fruit yield and natural preimmunity against citrus tristeza virus.

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Embrapa's contribution to the development of new plant varieties and their impact on Brazilian agriculture

Grape	14	BRS Lorena	It enabled significant gains for the farmers and agribusiness. The producer of this grape could earn up to 90% extra profit due to its superior quality.
Carrot	5	Brasília	It was the most successful example of vegetable breeding work for tropical adaptation. It has high-yielding potential, heat tolerance and high levels of resistance to soil-borne and foliar disease. It allowed the year-round availability of an inexpensive source of pro-vitamin A.
Peruvian Carrot	1	Senador Amaral	It is an early cultivar, productive and presents a more intense root color. It is widely used for processing items such as "baby food".
Tomato	12	BRS San Vito	It is an Italian-type hybrid. It was a commercial success due to its high fruit yield, multiple disease resistance and higher levels of antioxidant/nutraceutical carotenoid content lycopene.
Eggplant	1	Ciça	It is a hybrid with resistance to anthracnose and <i>Phomopsis</i> . It is one of the market leaders due to its high yield and hardness.
Melon	2	Eldorado 300	It was the first tropical cultivar with resistance to potyvirus. It was used as parental line of several commercial hybrids developed by private companies and it was widely grown in northeastern Brazil.
Hot and sweet peppers	6	BRS Sarakura	It is a jalapeño pepper type, with high productivity. It was developed in partnership with the private sector. It is one of the leading cultivars for production of pepper sauces.
Pumpkin and squash	2	Jábras	It is an interspecific Tetsukabuto-type hybrid with high fruit yield and hardness. It allowed domestic production of hybrids of this varietal segment.
Brassica	4	Repolho União	This cultivar is one of the most important sources of resistance to black rot of crucifers, being used in different breeding programs.
Sweet corn	5	Doce Cristal (BR-402)	It is one of the pioneer cultivars adapted to <i>Cerrado</i> region. It presents high field hardness, yield and resistance to <i>Helicoverpa zea</i> . It is suitable for processing and small gardens.
Onion	6	Alfa Tropical	It was the first onion cultivar adapted for cultivation under summer and rainy conditions.
Soybean	300	Doko	It contributed to the incorporation of vast <i>Cerrado</i> areas to the agricultural production. It is present in the pedigree of various soybean cultivars released in Brazil.
		BR 16	This cultivar has been grown in Brazil for several years, mainly due to its resistance to stem canker.
		BRS Valiosa RR	It is a glyphosate-tolerant transgenic cultivar with resistance to root knot nematodes. It presents great adaptability and high yield, occupying large areas of Brazilian <i>Cerrado</i> .
Beans	50	Pérola	It represents a milestone in the production and consumption of beans in Brazil and in the world. Besides its high productivity, it has upright plant architecture and it is resistant to angular leaf spot and fusarium wilt. It has accounted for 70% of the area cultivated with carioca-type beans. Sixteen years after its release, it remains one of the most widely grown cultivars in many regions of Brazil.
Cowpea	36	BRS Guariba	It was the first upright cultivar and it is largely responsible for the expansion of the cultivation of cowpea in the mid-west region. It was also the first to be exported, opening markets in several Asian and European countries.
		BRS Itaim	It was the first blackeye type cultivar, adapted to Brazilian conditions, which opened prospects for expanding exports of cowpea, mainly to the United States and African countries.
Peanuts	4	BR 1	It was released to meet the fresh market. It is the most popular cultivar in the Northeast region of Brazil.
Pea	14	Axé	It is a cultivar especially developed for the processing industry (canned and frozen), with high productivity and resistance to powdery mildew (<i>Erysiphe pisi</i>).
Lentil	2	Precoz	It is an early maturing cultivar, productive and adapted to cultivation in <i>Cerrado</i> region.
Chickpea	1	Cícero	It has large grains with higher commercial value. It has excellent adaptation for cultivation in <i>Cerrado</i> region.
Cotton	44	CNPA Precoce 1	It is a precocious fruiting cultivar, which made the crop viable for cultivation in the Northeast region under high pressure of cotton boll weevil (<i>Anthonomus grandis</i> , Boh.).
		CNPA ITA 90	It is the first cultivar used in large-scale farming in <i>Cerrado</i> region (over 90% hectareage). It is considered as the cultivar that consolidated the production of cotton in this geographic region.
Sunflower	5	Embrapa 122	It was developed aiming to attend the agricultural promoting programs for biodiesel production by family-based farms. It is expected to occupy around 100,000 ha from 2008 to 2012 crop seasons.
Castor bean	4	BRS Nordestina	It is recommended for family-based farms of the Brazilian semiarid. It is a cultivar with midsize seed and presents drought tolerance. Its yield potential is around 1,500 kg ha ⁻¹ yr ⁻¹ of seeds
Sesame	5	BRS 196	It presents yield potential of up to 2,500 kg ha ⁻¹ in irrigated conditions and 1,500 kg ha ⁻¹ under upland conditions, thus becoming an alternative for income generation in family farming.
Sisal	1	Hybrid 11648	It is mainly employed in intercropping with annual crops, as well as in the creation of goats and sheep. It encouraged small farmers to use fiber crafts as a way of adding value to the product.

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Oil palm	8	BRS Manicoré	Due to its resistance to fatal yellowing, it is the only alternative for the development of palm culture in areas with the presence of this disease. More than 10 million seeds have already been made available, which represents about 60,000 ha.
Guarana	18	BRS Amazonas e BRS Maués	These clones that present ten times higher productivity than the average of the traditional genotypes, with tolerance to anthracnose and supersprouting, two major diseases of culture.
Acai	1	BRS Pará	It was the first acai cultivar in the world. It presents early maturing and yield estimated at 10 ton ha ⁻¹ yr ⁻¹ , about twice the traditional average productivity.
Cassava	14	Formosa	It presents bacterial blight resistance, drought tolerance and high yield.
		Kiriris	It is resistant to root rot, and allowed the cultivation of cassava in places where the activity was abandoned due to this disease.
		BRS Dourada	It has yellow pulp and it is suitable for frying without precooking, since its soft roots prevent that the cassava chips break.
Potato	3	BRS Ana	It is a pink peel cultivar with high yield potential and suitable for fresh consumption and for processing.
Brachiaria	4	Marandu	Released in 1984, it is the most planted forage in Brazil, accounting for almost 70% of the commercial seed market. It has been an important alternative for the recovery and repair of degraded pastures.
Switchgrass	4	Mombaça	It is estimated that 7%, i.e. 7.4 million ha of the cultivated pastures are currently occupied with this cultivar.
Forage legumes	6	Estilosantes Campo Grande	It occupies an area estimated at more than 1 million hectares of pastures, intercropped with grasses, resulting in significant economic impact associated with the increased productivity and quality of cattle feeding.
		Feijão guandu BRS Mandarin	Its use in dairy heifers feeding, under experimental conditions, reduced the cost of feeding by 21%. It is also indicated for crop rotation and reclamation of degraded areas.
Elephant grass	1	Pioneiro	It was the first elephant grass cultivar for grazing use, being an important alternative to the intensification of livestock production in small farms.
Winter forage	4	Azevém BRS Ponteio	This cultivar presents 7% higher yield than the ryegrass. It represents the first sound result of resumption in forage breeding in temperate regions of the country.
Other forage crops	3	<i>Paspalum</i> Pojuca and <i>Andropogon</i> Planaltina	These cultivars are used in the diversification of pastures. More than 40 genera of forages have been evaluated in the research program of Embrapa.

development and diversification of Brazilian agribusiness have demanded the release of cultivars with traits that allowed for adaptation to different environmental conditions and new production systems. In this context, the role of Embrapa in cultivar business has diversified beyond the production and market of seeds and propagules. Currently, licensing of cultivars and lines is also part of its business portfolio as well as the establishment of partnerships with the private sector aiming to develop conventional cultivars as well as transgenic events.

Embrapa is dedicated to the breeding of many species that even though not having the economic expression of major commodities such as soybeans, corn and cotton, they are important crops for specific segments of agribusiness and family-based farming in the country. At the present moment, the corporation is responsible for the production of basic seeds/propagules of 276 cultivars of 40 species (Figure 4) and negotiates an average of 1,300 licensing agreements per year. Embrapa's participation in the National Plant Variety Protection system is significant, with approximately 31% of the total protected cultivars (Figure

5). It is noteworthy that Embrapa is the only corporation which obtained protection in more than 40 different plant species. The offer of cultivars of a wide range of agricultural species, which are interesting for business and family-based agriculture, or present a local, regional or national importance, is strategic for the development of the national seed and propagules industry.

Embrapa also plays an important role in government programs to support family-based farming. In the period from 2006 to 2011, for example, it distributed seeds to more than 300,000 farmers in the Northeast region. This work was done in partnership with the Ministry of Agrarian Development and the Ministry of Social Development, which allowed farmers to have access to technological advances represented by new varieties of corn, beans, cowpea, cotton and castor beans developed by Embrapa for the Northeast Region of Brazil.

Embrapa's partnerships with foundations, Brazilian seed companies or associations of seed producers have been the business model most used by the institution for

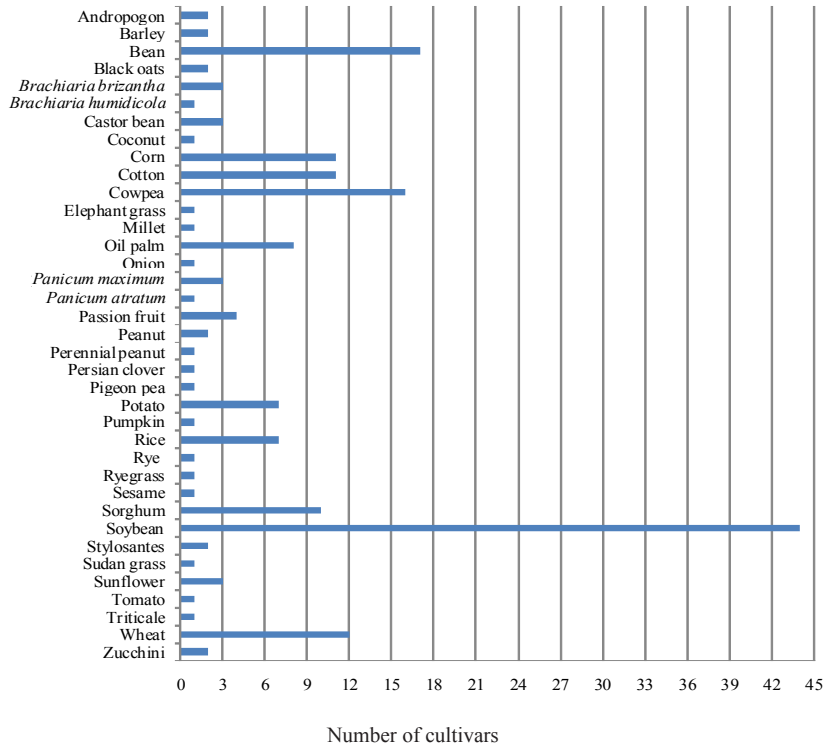


Figure 4. Number of improved cultivars belonging to the main plant species currently marketed by Embrapa.

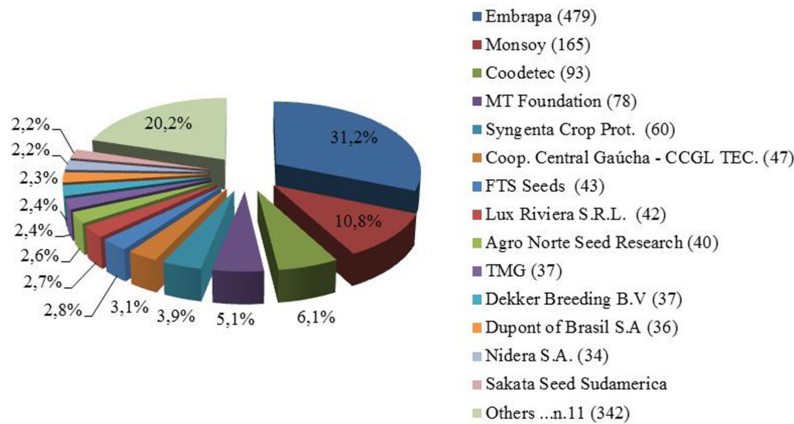


Figure 5. Number of cultivars protected by Embrapa and other public and private institutions in the Brazilian market.

the development of new varieties of soybean, wheat, cotton, triticale, forage and tomato. In these partnerships, the partner is involved in the final stages of breeding programs, contributing to a network of trials that allows for the release of cultivars for various environmental conditions in the country. Through promotion and commercialization by the producer and partner companies, Embrapa cultivars are made available and marketed nationwide.

A historical example of great importance in partnership was the establishment of Unimilho in 1989. This was a unique, franchising-like arrangement, comprising 28 associated seed companies, which allowed Embrapa to occupy more than 15% of the corn hybrid domestic market share with the cultivar ‘BR 201’ (Machado Filho and Matias 1995). Due to the excellent performance and acceptance of ‘BR 201’, Embrapa contributed to the increase in the

number of companies operating in the competitive sector of corn seeds, which resulted in price reduction of hybrid seeds in that period.

Partnerships with large agribusiness corporations have also been signed with the aim of expanding the reach of Embrapa in agriculture and increasing availability of technological solutions to Brazilian farmers. Among the major corporations that maintain partnership with Embrapa, Monsanto do Brasil, has implemented agreements for use of its herbicide resistance technology on Embrapa's soybean breeding program. Embrapa also has partnership agreements with BASF, Syngenta and Dow AgroSciences for the joint development of technologies, many of them focusing on the market of cultivars. The partnership with BASF allowed the development of soybean Cultivance and rice BRS Sinuelo CL products, which are resistant to imidazolinone herbicides, thus representing alternatives for weed control by the farmers. Projects of scientific-technical cooperation, currently formulated in open innovation system, have led to the integration of technological development teams, allowing the creation of differentiated models of distribution and commercialization of seeds and propagules.

SOCIAL, ECONOMIC AND ENVIRONMENTAL IMPACTS OF THE PLANT BREEDING PROGRAMS CONDUCTED BY EMBRAPA

Calculating and assigning benefits and impacts to such a wide range of plant breeding programs developed by Embrapa is another complex challenge (Alves et al. 2002). Despite this difficulty, Embrapa has tried to use and improve, since 1997, the concept of "social balance", which was adapted to estimate the contribution of its technologies and products for the Brazilian society. This instrument tries to highlight the multidimensional impacts of agricultural research, estimating its economic, social, and environmental contributions. In 2011, the corporation selected for the calculation of its social balance a sample of 114 technologies and 163 cultivars (http://bs.sede.embrapa.br/2011/bs_2011.pdf), which were developed with multiple partners and transferred to society. A profit of R\$ 17.76 billion has been estimated for 2011, indicating that to every R\$ 1.00 invested in Embrapa by the Federal Government it returned R\$ 8.62 for the society.

One of the main impacts of the production increase and diversity of Brazilian agriculture over the past four decades has been the assurance of a permanent supply of low-cost food for the Brazilian society. Consumers

are the main beneficiaries of the agricultural revolution that occurred in the country, by having food in quantity, quality and low prices (Bonelli 2002). The prices of staple foods currently paid by consumers decreased to almost half of the amount paid 30 years ago, favoring the poorest people, who spend most of their income on food (Contini et al. 2010). Plant breeding had an outstanding participation in achieving food security in the country, since its advances in adapting the various crops to the tropical and subtropical conditions allowed the expansion of the cultivated area and achievement of significant yield gains by most crops grown in Brazil. With major advances in production efficiency, Brazilian agriculture was able to contribute to the reduction of inflationary pressures and to mitigation of social inequalities. Moreover, diversification and intensification of agricultural exports over the past decades have generated economic surpluses and expanded the investment capacity of the country (Brazil 2010, Contini et al. 2012).

The germplasm adaptation and the development of cultivars able to withstand the challenging environments for agricultural production in the tropics was one of the main impacts of Embrapa breeding programs. This research contribution was vital, because unlike temperate regions, the tropical environments present a wider range of biotic and abiotic stresses for agriculture, livestock, and forestry (Paterniani 2001). Brazil does not have crop growing areas similar to that of the North American Corn Belt, which are homogeneous with favorable climate conditions, topography and soil fertility. High soil acidity, low nutrient availability in the soil, recurrent drought spells, the incidence of extreme temperatures, attacks of pests and diseases, and competition with weeds are some of the agricultural challenges commonly occurring in the country.

A successful example of the economic viability of agriculture, supported in most part by the development of locally-adapted cultivars, was the occupation of the Brazilian *Cerrado*. This region (predominantly located in Central Brazil) is a complex of about 200 million hectares characterized by acidic soils with low availability of micro and macronutrients. Forty years ago, this region was considered unsuitable for agricultural production. Despite these limitations, Brazilian researchers were able to generate a wide array of technological solutions that allowed the economic incorporation of this region to the crop production landscape. The employment of practices of soil remediation and construction of fertility, combined with the breeding of adapted plant cultivars, mechanization and control of pests and diseases, among other innovations, enabled the *Cerrado* region as the most important frontier

for expansion of agriculture in the country. Innovations in the field of genetics and plant breeding generated by Embrapa and its various partner institutions also contributed to stimulate the development and improvement of a great range of technological inputs, processes and practices that were at the base of the agricultural revolution occurred in Brazil over the past decades. Plant breeding research contributed significantly to the development of modern production systems, adding stress tolerance and nutrient use efficiency, enabling minimum tillage practices. Crop management based on minimum and non-tillage system, for example, has been used for decades in millions of hectares of distinct field crops in Brazil, with a significant contribution in reducing erosion, improving overall soil quality and avoiding groundwater depletion. Likewise, the biological nitrogen fixation by means of inoculation of diazotrophs has enabled a significant reduction in the application of chemical fertilizers in soybeans, with significant reduction of groundwater contamination by leaching of nitrogen. The biological control routinely used in various crops, such as soybeans, sugar cane, cotton and fruit orchards has also reduced the demand for chemical control of pests and diseases in various integrated management systems. These technologies have positive impacts on the environment, quality of life of rural workers, safety and quality of agricultural products. Responsive cultivars with higher levels of adaptation and superior agronomic traits are important carriers of new practices, processes and technologies for production systems. Mechanization, no-tillage system and crop integration are examples of practices that were made possible, in large scale, with the contribution of genetic improvement programs.

Embrapa also gave significant contributions to the development of the national seed industry during the 1980s and 1990s, creating conditions for consolidation of numerous private companies, including the ones that have developed the ability of organize and consolidate their own competitive breeding programs. Embrapa has also developed strong partnerships with universities, contributing to the consolidation of major graduate programs that had impact in academia as well as in the development of public and private breeding programs. A significant number of Masters and Doctoral thesis have been developed under the supervision or co-supervision of Embrapa researchers over the last decades, in plant breeding and related subjects, focused on problems of Brazilian agriculture, and using the infrastructure of research and development of the organization, in perfect integration with the universities.

PLANT BREEDING PROSPECTS AT EMBRAPA

In contrast with food-producing countries located in temperate climates, Brazil has most of its territory in the tropics, with unique soil and climate characteristics, intense biotic and abiotic stresses, complex agrarian structure and diverse patterns of technological infrastructure and logistics. Thus, innovations in genetics and plant breeding to develop improved seeds and adapted production systems will continue to be important to Brazil, especially in face of the challenges of increasing food demands in the predicted scenarios of climate changes (Assad et al. 2008).

It is a fact that there are national and international pressures on the conservation of natural resources and new demands for reducing deforestation to minimize the effects of greenhouse gases and to conserve biodiversity. This increases the demand for agricultural practices based primarily in increases in productivity, both in crops and in livestock production systems. Brazilian agriculture will require advances in diversification, value-adding traits, yield, safety and quality with speed and efficiency superior to those achieved so far. Due to the increasing interest and need for diversification and adding value to agriculture in the form of new food products, bioenergy, fiber, medicines and biomaterials applicable to various industries, the challenges of plant breeding will increase, as well as the need of enhancing research in genetics and exploitation of germplasm collections, aiming to diversify crop species, systems and processes.

These conditions outline the future of agribusiness organized around technological aspects geared to save natural resources and generate environmental services in order to process biological structures in new products, and to add value by incorporating specific attributes. All these challenges are quite intensive in scientific and technical knowledge at the interface of multiple disciplines, and its excess will depend on complex systems of technical-scientific, management and marketing information. Therefore, breeding should try to anticipate the demands of agribusiness in the bioindustrial era, identifying potential development of radical and incremental innovations that lead Brazilian agriculture to a new competitive level (Lopes and Contini 2012). Following, there are some trends that will receive increasing attention from Embrapa:

- a) *Genetic improvement and sustainability in agriculture* – agricultural production systems should seek ways of accessing and using, in a rational way, the environmental inputs (water, soil, biodiversity) and environmental services (recycling materials, water conservation and efficient use, air quality,

among others) needed for safe and sustainable production. To ensure the future sustainability of agricultural activities, it will be necessary to invest in scientific and technological knowledge in order to develop innovative production systems, aimed at increasing the productivity of natural resources and environmental services used by agribusiness. This implies not only the intensification of production systems for classic routes, but also routes in search of innovative technology, in relation to the models and production strategies, intensive use of advanced genetics, new inputs, among others.

b) *Genetic improvement and global climate change* – The global simulation models, despite being still limited, suggest major vulnerabilities in the tropics due to extreme events that are becoming more frequent, such as temperatures rising and changes in rainfall distribution and intensity (Marengo 2007, Assad et al. 2008, Ramalho et al. 2009). From the agriculture standpoint, these events may involve loss of biodiversity, changes in water availability, changes in the ecology of pests and diseases, etc. With this perspective, the competitiveness of Brazilian agriculture will depend crucially on knowledge and technology to evaluate the vulnerabilities of the major biomes and risks associated with agribusiness, on optimized models to understand and predict likely changes and their speeds, and on the development of varieties and systems adapted to the new conditions.

c) *Genetic improvement and integrated systems* – Technologies that enable the intense use of natural resources should receive more attention in the future. Dias-Filho (2011) reported that about 70 million hectares of pastures/grasslands in Brazil are unproductive and degraded or in process of degradation. These are the ideal areas for expansion of agriculture, livestock and Brazilian forestry base, without the need for further deforestation. The technologies of integrated crop, livestock and forest (ICLF) allowed the development of multiple productive activities in the same area, building/maintaining soil fertility through such integration. The expanded use of integrated systems requires large research effort, including genetic improvement, which should seek to develop cultivars adapted to complex production models.

d) *Genetic improvement and biological security* – One of the critical challenges for Brazilian agriculture is the movement of organisms or exotic invasive species from one region to another, depending on market dynamics, transportation, transit and tourism. Globalization of pests leads to displacement of organisms from one region to another, intentionally or not, with significant potential for negative economic, environmental and social impacts. Preventive genetic improvement is crucial for anticipating and minimizing the impact of the entry of quarantine pests in the country, with the support of varieties adapted to biotic stresses that do not exist in our territory. The emphasis on technological innovation is critical to the protection of our agriculture, to meet the diverse demands of importing countries, and to line up with strict compliance standards that are consolidated in the international arena.

Genetic improvement has a crucial role for mobilization of genetic variability in the development of safe alternatives to support the Brazilian biological security strategies (resistance/tolerance to various biotic stresses).

e) *Genetic improvement and food-nutrition-health integration* – The crisis affecting health systems and social security worldwide indicates the necessity of migrating quickly from the paradigm of curing to that of preventing human diseases and ailments. The knowledge about biodiversity, genetics, genomics and recent advances in medicine has the potential to strengthen the links between physical and mental health, nutrition and food (Johns and Eyzaguirre 2006, Ash et al. 2012). There is a growing interest in foods with a low risk of harm to the population's health, which can prevent disease and improve the food and nutrition standards. Genetic improvement is expected to become a major source of nutritional foods in addition to new features that will contribute to advances in food-nutrition-health integration.

f) *Genetic improvement and changes in demands of final consumers* – Changes on eating habits and preferences of consumers are evident, especially the middle and upper classes. The population aging, the quest for a healthier life, the increased participation of women in the workforce, the smaller size of families, the standardization of consumption patterns due to the global economy, and the spread of regional products are impacting the consumption habits, affecting the demand for food and processing items. An important market trend is the willingness of consumers to pay more if the product is a result of an environmental and socially sustainable production process. Consumers are the major target of agribusiness and agri-food systems in the world. This large diversification of required attributes in agribusiness products will have direct consequences on plant breeding and its products.

g) *Pre-breeding and expansion of genetic variability* – Most of the cultivars of species of economic importance released in the market present narrow genetic base (Duvick 1990, Cuevas-Péres et al. 1992, McCouch and Tanksley 1997). In this scenario, the implementation of strategies to increase genetic diversity is of fundamental importance for the development of cultivars with tolerance to biotic and abiotic stresses, and the incorporation of new crop functionalities to farming systems and agribusiness. Pre-breeding programs will remain strategic as providers of genetic variability for Embrapa and for the market, fulfilling the essential role of making useful the variability preserved in the organization's germplasm banks (Lopes et al. 2011). Studies in this area should anticipate future needs and concentrate on the development of methodologies for better use of variability and improve efficiency in the identification and exploitation of desirable traits.

h) *Development of bio-based assets* – The recent advances in biology open up significant possibilities for potential use of the vast genetic variability on biodiversity, germplasm

and breeder's working collections. This impact may be even greater with the use of new advanced biology tools and with the organization and provision of information associated with the collections. Breeding programs can extend their functionality by developing, in addition to populations, lines and commercial cultivars, genetic resources suited to the characterization of important biological functions and to the discovery of mechanisms, processes and tools (e.g. cloned genes and regulatory elements) that might boost cultivar development programs. An alternative for public sector participation in highly competitive segments is converting part of breeding efforts to pre-technological segments, providers of tailor-made variability (lines, testers or improved populations) or assets (e.g. new genes, protected promoters and processes) that offer opportunities for public sector participation in pre-competitive or open innovation initiatives with public and private partners.

i) *Training and development of new skills* – Conventional breeding has been historically considered as a highly integrated activity. However, the growing understanding of the interactions among systems (organisms and the physical environment) and the new advances in biology will provide alternatives for potentiating the amount and quality of knowledge available for the applied breeding programs. The training requirements will need to evolve rapidly in order to internalize these changes into the conventional breeding procedures. The areas of plant physiology, quantitative genetics and biochemistry are incorporating new tools derived from the recent advances in molecular and cellular biology, bioinformatics and genomics (Kafatos and Eisner 2004). Data management and analysis will be an increasing challenge due to the large amount of information that is being generated by these new technologies. This new generation of breeders will need to incorporate these novel approaches in order to participate in more complex innovation programs, and to access new concepts and tools. To remain competitive Embrapa and other public institutions need to encourage and be involved in all aspects of plant breeding training and capacity building, including the establishment of multidisciplinary teams and helping with integration of new skills and concepts into the plant breeding practice.

FINAL REMARKS

According to recent studies of FAO (2011), to feed a population of over 9 billion people by 2050, the world will have to produce 3 billion tons of cereals (current production is around 2.1 billion) and 470 million tons of meat (instead of the current 200 million). This will be a difficult task in a planet with increasing urbanization and social inclusion. Therefore, it is urgent to increase food production, with safety and quality. Besides food, agriculture is increasingly demanded in the supply of other raw materials that are necessary for human welfare.

The society expects the contribution of agriculture in the production of biomass and renewable energy (bioenergy) by replacing part of the finite resources of fossil energy, and new uses of agricultural products and by-products of bio-industrial sectors in other sectors, such as green chemistry. Only diversified research programs in plant breeding, and an effective combination of public and private efforts, focusing on short, medium and long term objectives, will ensure that our agriculture remains competitive and able to respond quickly to these challenges.

Despite the great success of plant breeding programs from Embrapa and other Brazilian public institutions (Venkovsky and Ramalho 2000), many events have changed the balance of this segment of innovation, changing public-private relations and offering a wider diversity of alternatives for the cultivars and seeds market (Castro et al. 2004). Some of these events include: (1) the implementation of the legal framework for knowledge protection, represented by the laws of industrial property (patents) and cultivar protection in the second half of the 1990s; (2) the technical advances in biotechnology, especially genetic engineering, based on proprietary technologies; (3) the high costs of the processes of deregulation and commercial viability of transgenic products, which favors large corporations and hinders public sector participation in this innovation markets; (4) the market dynamics of genetics, biotechnology and cultivars that, due to the growth of Brazilian agriculture and the opening of new technological perspectives, attracts for the country large corporations in the sector, making it a very competitive market; (5) the challenges for implementation, in the public sector, of business models compatible with the dynamics and competitiveness of this new market of cultivars, which involves vertical integration (genetics + transgenic + chemical + services) and marketing practices hardly adaptable to the reality of public research and development institutions (Castro et al. 2006).

All these events impact on the relationships, the performance and the landscape that public institutions occupy in very competitive plant genetics and breeding markets, especially for commodity crops such as soybean, corn, and cotton. The same situation will soon be extended to other species, such as rice, wheat, sorghum and forages. Any more detailed analysis of the dynamics of the seed sector of large commodities, in an international scope, will show that in almost all countries with advanced agriculture, such as Brazil, the presence of the public sector in the most dynamic and competitive segments is minimal or nonexistent. Embrapa is one of the few public organizations around the world that still coordinates

structured breeding programs for all major commodities, while maintaining great diversity of breeding programs of other species.

The decrease over the last few years in the share of Embrapa and other public organizations in the commodity seed market was somehow expected, due to the more intense global process of merging, acquisition and incorporation of smaller companies by the large seed and biotechnology companies. The public sector relies on private companies that multiply and release to market their innovations in plant breeding. Most Brazilian seed companies were unable to survive in this new competitive environment, eventually disrupted or bought by large private corporations. In summary, the new configuration of the seed market in Brazil makes it quite difficult the survival of public research programs in genetics and breeding of commodities, unless creative and viable solutions are devised in the near future.

Embrapa has been establishing a series of procedures in order to fit its breeding programs in this new context, prioritizing those crops positioned in more competitive markets – such as soybeans, corn and cotton. Studies and analyses are under way and will provide information and

recommendations to guide the decision-making process to implement the strategies necessary for repositioning of the organization's programs in the seed market. It is anticipated for the coming years that changes in the organization of breeding programs and in business strategies will occur in order to ensure the permanent presence of Embrapa and its partner institutions as players in the seed market.

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Contribuição da Embrapa na produção de novas cultivares de plantas e seu impacto na agricultura

Resumo – *Os programas de melhoramento genético desenvolvidos pela Embrapa e parceiros contribuíram significativamente para os principais avanços qualitativos e quantitativos obtidos pela agricultura brasileira nos últimos 40 anos. Neste artigo, apresenta-se uma visão da diversidade de espécies e múltiplos objetivos estabelecidos por esses programas, ressaltando algumas contribuições da instituição para o setor agrícola. Apresenta-se ainda uma discussão sobre o impacto econômico, social e ambiental das cultivares lançadas pela Embrapa no mercado brasileiro, assim como uma análise do papel da instituição no melhoramento de cultivares no presente e no futuro. Os riscos, oportunidades e desafios para o trabalho de melhoramento genético vegetal são discutidos, considerando as mudanças recentes e as inovações observadas no mercado de sementes no Brasil.*

Palavras-chave: *Melhoramento genético vegetal, inovações tecnológicas, mercado de sementes, cultivares.*

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