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Editors

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Editors
Felipe Lopes da Silva
Federal University of Viçosa
Viçosa, Minas Gerais
Brazil

Aluízio Borém
Federal University of Viçosa
Viçosa, Minas Gerais
Brazil

Tuneo Sediyama
Federal University of Viçosa
Viçosa, Minas Gerais
Brazil

Willian Hytalo Ludke
Federal University of Viçosa
Viçosa, Minas Gerais
Brazil

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Foreword

Soybean is the fourth most widely grown crop in the world. Originally from China it is a major crop in the USA, Brazil, Argentina, China, and many other countries. The improvements undergone by soybeans are not only a self-success, but it also triggers new technologies to other crops and regions around the world. As a source of oil, biodiesel, etc., soybeans are currently grown from low to high latitudes.

This book addresses the most recent and best technologies applied to soybean breeding. Some of the authors such as Dr. Vernetti and Dr. Sedyiama were pioneers in shaping the current generation of soybean breeders in countries like Brazil. This is a great opportunity to celebrate. Dr. Francisco de Jesus Vernetti, a personal friend and former major advisor, introduced and encouraged me to work under Dr. Edgar E. Hartwig, the icon in soybean breeding. Dr. Hartwig's contribution to soybean breeding in the USA and Brazil cannot be overemphasized. Dr. Hartwig was the most prominent soybean breeder in history. He was the first scientist to adapt this crop to areas closer to the equator, understanding soybean flowering in short days. This trait, today called "long juvenile stage," is well studied and its genetic control well understood (a few recessive genes), which allowed its use to develop cultivars for new agricultural frontiers in countries like Brazil and elsewhere.

Brazil is the second largest soybean producer and this is due to the breeding done with this crop in the last 60 years. Some aspects distinguish the work done in Brazil, since the crop had to be adapted to marginal areas with diverse cropping systems. Brazilian breeders had the additional challenge to develop cultivars resistant to the highly aggressive and prevalent pests typical of tropical regions, besides dealing with the soil acidity and seed quality, among other defies.

Another interesting area is breeding for nutritional quality, especially for oil and protein, besides reduction of antinutritional factors.

The large genetic progress observed in the last decades was mainly due to the mechanization of the breeding operations in planting, evaluating, and harvesting field trails, besides the use of computer power increasing the ease and speed to organize and analyze data and spreadsheets.

The GM cultivars made it easier to control weeds and are very promising in pest control. Additionally, the genetic studies and detection of molecular markers will also contribute to soybean breeding in the near future.

As always, breeders are optimistic and I personally believe that traditional breeding, helped by new tools, will continue to be a great asset to soybean future.

Romeu Kiihl

Synopsis

This book was written by experts, in a very detailed way, and aims to provide support to soybean breeders, seed farmers, and students interested in the techniques and methods for improvement of this species. Here we describe the most modern and recent technologies applied to the development of new soybean cultivars. It is, therefore, an essential work to all those interested in the improvement of this species.

Contents

Contributors

Lilian Cristina Andrade de Araújo Teixeira, D.Sc. State University of São Paulo (UNESP), São Paulo, Brazil

Carlos Alberto Arrabal Arias, M.S., Ph.D. Embrapa Soja, Londrina, Parana, Brazil

Leonardo de Azevedo Peixoto, M.S., D.S. The Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Rosângela Maria Barbosa Department of Agronomy, Federal University of Viçosa, Viçosa, Brazil

André Ricardo Gomes Bezerra, M.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Leonardo Lopes Bhering, M.S., D.S. The Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Aluízio Borém, M.S., Ph.D. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Adriano Teodoro Bruzi, M.S., D.S. Federal University of Lavras, Lavras, MG, Brazil

Thays Vieira Bueno, M.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Pedro Crescêncio Souza Carneiro, M.S., D.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Rita de Cássia Teixeira Oliveira, M.S. Campo Experimental Bacuri, Viçosa, Minas Gerais, Brazil

Sueli Ciabotti, D.Sc. Federal Institute of Education, Science and Technology of Triângulo Mineiro, Uberaba, Brazil

Cosme Damião Cruz, M.S., D.S. The Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Stênio Andrey Guedes Dantas Department of Agronomy, Federal University of Viçosa, Viçosa, Brazil

Murilo Viotto Del Conte, M.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Marcelo Fernandes de Oliveira, M.S., Ph.D. Embrapa Soja, Londrina, Parana, Brazil

Paulo Afonso Ferreira, M.S., D.S. Federal University of Viçosa—Campus Universitário do Araguáia, Barra do Garças, Brazil

Silvana da Costa Ferreira, M.S., D.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Amilton Ferreira da Silva, M.S., D.S. Federal University of São João Del-Rei (UFSJ), Campus de Sete Lagoas, Sete Lagoas, Minas Gerais, Brazil

Ana Cristina Pinto Juhász, D.Sc. Agricultural Research Company of Minas Gerais (EPAMIG), Uberaba, Brazil

Laércio Junio da Silva, M.S., D.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Rita de Kássia Siqueira Teixeira, M.S. Federal University of Lavras, Lavras, MG, Brazil

Felipe Lopes da Silva, M.S., D.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Alisson Santos Lopes da Silva Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

André Luiz Lourenção, M.S., D.S. Phytosanitary Center, Agronomic Institute of Campinas, Campinas, São Paulo, Brazil

Willian Hytalo Ludke, M.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Éder Matsuo, M.S., D.S. Federal University of Viçosa - Campus Rio Paranaíba, Rio Paranaíba, Brazil

Antonio Orlando Di Mauro, M.Sc., D.Sc. Universidade Estadual Paulista, Jaboticabal, São Paulo, Brazil

Pedro Patric Pinho Morais, M.S., D.S. Monsanto Brazil, São Paulo, SP, Brazil

Fabiana Mota da Silva, M.Sc., D.Sc. Universidade Estadual Paulista, Jaboticabal, São Paulo, Brazil

Heloisa Rocha do Nascimento Department of Agronomy, Federal University of Viçosa, Viçosa, Brazil

Felipe Maniero Nazato, M.S. Department of Genetics, College of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba, São Paulo, Brazil

José Aírton Rodrigues Nunes, M.S., D.S. Federal University of Lavras, Lavras, Minas Gerais, Brazil

Guilherme de Sousa Paula Department of Agronomy, Federal University of Viçosa, Viçosa, Brazil

José Baldin Pinheiro, M.S., D.S. Department of Genetics, College of Agriculture "Luiz de Queiroz", University of São Paulo—ESALQ, Piracicaba, São Paulo, Brazil

Magno Antonio Patto Ramalho, M.S., D.S. Federal University of Lavras, Lavras, Minas Gerais, Brazil

Marcos Deon Vilela de Resende, M.S., D.S. Brazilian Agricultural Research Corporation/Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Haroldo Silva Rodrigues, M.S., D.S. The Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Renato Domiciano Silva Rosado, M.S., D.S. The Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Hamilton Carvalho dos Santos Júnior Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Ivan Schuster, M.S., D.S. Dow AgroSciences, Cravinhos, São Paulo, Brazil

Tuneo Sediyama, M.S., Ph.D. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Francisco Charles dos Santos Silva, M.S. Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Reginaldo Castro de Souza Júnior Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

Francisco Terasawa FT Sementes, Ponta Grossa, Parana, Brazil

José Maurício Terasawa, M.S., Ph.D. FT Sementes, Ponta Grossa, Parana, Brazil

Milene Möller Terasawa, M.S., D.S. FT Sementes, Ponta Grossa, Parana, Brazil

Sandra Helena Unêda-Trevisoli, M.Sc., D.Sc., Ph.D. Universidade Estadual Paulista, Jaboticabal, São Paulo, Brazil

Natal Antonio Vello, M.S., D.S. Department of Genetics, College of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba, São Paulo, Brazil

José Djair Vendramim, M.S., D.S. Department of Entomology and Acarology, College of Agriculture "Luiz de Queiroz", University of São Paulo, Piracicaba, São Paulo, Brazil

Francisco de Jesus Vernetti, M.S. Embrapa Clima Temperado, Pelotas, Rio Grande do Sul, Brazil

Francisco de Jesus Vernetti Junior, M.S., D.S. Embrapa Clima Temperado, Pelotas, Rio Grande do Sul, Brazil

Leonardo Volpato Department of Agronomy, Federal University of Viçosa, Viçosa, Brazil

Chapter 1
Economic Importance and Evolution of Breeding

Francisco Charles dos Santos Silva, Tuneo Sediyama, Rita de Cássia Teixeira Oliveira, Aluízio Borém, Felipe Lopes da Silva, André Ricardo Gomes Bezerra, and Amilton Ferreira da Silva

Abstract Originating in northeast China, soybean (*Glycine max* (L.) Merrill) in the last decades has become the main oilseed in the world due mainly to being a great source of vegetable oil and protein. This crop currently occupies an area more than 118 million hectares worldwide. Due to the projections for the increase of the world population and the high purchasing power of this, the demand for the soybean grain will not decrease in the next years. In Brazil, soybean found adequate conditions for its development in the South. From this region, since the 1970s, soybean has been expanding in the Brazilian savannah, called Cerrado, a process known as the "tropicalization of soybean". The genetic breeding of the species was one of the main factors responsible for the success of its expansion in Brazil. The evolution of soybean genetic breeding in Brazil can be divided into two phases. The first extends the introduction of the crop until the mid-1980s, marked by the participation of the public sector in the development of varieties, seed supply and technology transfer. This period was mainly marked by the adaptation of the soybean to the conditions of the Cerrado and regions of low latitudes. In the 1990s, a new phase for the soybean breeding in Brazil was started, which was marked by the participation of large groups of international capital. This period has been seeking, in addition to the

F.C. dos Santos Silva, M.S. (✉) • T. Sediyama, M.S., Ph.D. • A. Borém, M.S., Ph.D.
F.L. da Silva, M.S., D.S.
Federal University of Viçosa, Viçosa, Minas Gerais 36570-900, Brazil
e-mail: fcasantossilva-ma@hotmail.com; tuneo@ufv.br; borem@ufv.br; felipe.silva@ufv.br

R. de Cássia Teixeira Oliveira, M.S.
Campo Experimental Bacuri, Viçosa, Minas Gerais, Brazil
e-mail: cebacuri@uol.com.br

A.R.G. Bezerra, M.S.
Fundação MS Para Pesquisa e Difusão de Tecnologias Agropecuárias, Maracaju, Brazil
e-mail: bezerra.agro@yahoo.com.br

A.F. da Silva, M.S., D.S.
Federal University of São João Del-Rei (UFSJ), Sete Lagoas Campus, Sete Lagoas, Minas Gerais, Brazil
e-mail: amiltonferreira@ufsj.edu.br

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development of adapted and productive varieties, new materials of greater market value from the development of transgenic events.

Keywords *Glycine max* (L.) Merrill • Tropicalization of soybean • Soybean breeding • Soybean yield

Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the most important legumes in the world, especially for Brazil, which is the second largest producer in the world, due to an entire productive and technological chain developed around this species.

The crop originated in the northeastern region of China, but, in Brazil, the first soybean commercial crops were conducted in the southern region. From this region, since the 1970s, soybean crops have been expanding over the Brazilian Savanah, currently occupying areas that span the country from South to North.

The success and expansion of soybeans in Brazil are due to several factors, including the breeding of the species, with the development of more productive cultivars, adapted and resistant to various diseases.

Economic Importance

The economic importance of soybeans, worldwide, is due to the fact that the crop is an excellent source of vegetable oil and protein, with contents around 20 and 40%, respectively, whose production system has already been established.

According to the USDA (2015), world soybean production in the 2014/2015 crop season was 317.25 million tons, covering an area of 118.135 million hectares. In Brazil, in the 1960s, soybeans were only relevant in the southern region; however, after 55 years, production has reached 95 million tons in 31.57 million hectares, which places the Brazil as the second largest producer and the world's largest exporter of this crop.

In Brazil, the great expansion of soybean from the South Region to the Cerrado Region occurred in the 1970s. According to Bonato and Bonato (1987) and the MAPA (2015a, b) reports, from the 1969/1970 crop season to 2015, the crop production in the main producing states of Brazil has undergone significant increases. In Rio Grande do Sul, production has increased from 976,807 to 6,117,000 tons, from 90,086 to 3,957,000 tons in São Paulo, from 52,998 to 318,900 tons in Santa Catarina, from 368,006 to 14,766,000 tons in Paraná, in Minas Gerais it has gone from 1806 to 8159 tons, from 25 to 281,800 tons in Bahia, from 9817 to 807,300 tons in Goiás, in Mato Grosso, which until 1977 formed a single state with Mato Grosso do Sul, production increased from 8159 to 1,778,200 tons, whereas, in Mato Grosso do Sul production reached 8159 tons. In Maranhão, the first production record dates from 1977/1978 crop season, with a production of 55 tons, and reached 2,057,700 tons in the 2014/2015 crop season.

In recent years, the soybean production chain has had a large share of the Brazilian trade balance. Revenue from exports of soybeans and their by-products, such as meal and oil, in the 2014, exceeded US$ 31.4 billion, making soybeans the main export item in Brazil (MAPA 2015a, b).

Its economic importance is reflected in some social aspects of Brazil, that is, for each job generated by soybeans, the number of workers rises to 12.66, when taking into account the entire grain production chain, without accounting for the trade and rendering of services. The social impact of soybean production can also be measured by salary income, that is, for each real paid as salary in the field, the amount rises to R$ 33.23, when adding up the entire production chain (MTE 2010).

One of the factors to which the success of soybeans can be attributed is the increase in the world population, which grows at a rate of 70 million inhabitants per year; the increase in income per capita, which is associated with increases in the consumption of animal protein, which, in most part, is produced from soybean meal. Moreover, alternative products can be produced from soybeans, such as raw material for paints, lubricants, plastics, etc.

Due to the quality of the soybean protein and its relatively low production cost, this oilseed has become important as a source of protein supplementation, especially in developing countries. Soybean is the main source of protein meal in the world. In total, more than 188 million tons are produced, equivalent to 67% of the total supplied worldwide. Among the sources of vegetable oils available, soybean oil accounts for 56% of the total supply, which corresponds to 281 million tons (Bezerra et al. 2015).

In Brazil, soybean contributes to the incorporation of biodiesel into the energy mix. In 2013 it became mandatory, by law, to increase from 2 to 5% the amount of biodiesel in diesel oil. To date, soybean oil has been the main raw material for the production of biodiesel, followed by animal fat and cotton oil. In 2015, of the 2.6 million cubic meters of biodiesel produced, 78% derived from soybean oil (ABIOVE 2015).

In the coming years, the world's population and purchasing power will continue to grow in emerging economies and, especially, in Asian countries, which concentrates the highest consumption potential. Studies forecast that, by 2050, the earth's population will reach nine billion, which will demand 333.674 million tons of food (Alexandratos and Bruinsma 2012). Due to the great importance of soybeans in animal feed, in addition to its many industrial applications, the demand for its grain will not decrease in the coming years. In this context, the future scenario for Brazilian soybean is extremely promising.

Projections from MAPA (2015a, b) estimate that in 2024/2025 Brazilian soybean production will reach 126.2 million tons, which represents an increase of 32.8% compared to 2014/2015 crop season. Exports will be close to 66.5 million tons, an increase of nearly 42.1%. The production of soybean meal is expected to increase by 26.2% and that of oil by 21.1%. Exports of meal will increase by 17.4% between 2014/2015 and 2024/2025, while oil exports are expected to fall by 6.5%. Domestic consumption is expected to be the main factor to boost soybean oil

production in the coming years, which is expected to grow at the end of the decade to close to 8.5 million tons, a 30.6% increase in relation to 2014/2015 crop season.

Such level of perspective of soybean growth in Brazil is due to the increase in global demand and the fact that few countries are able to supply it. The USA and Argentina, for instance, will not be able to increase the area planted like Brazil. Moreover, the need to produce other crops and livestock activity prevents them from expanding the soybean area (Bezerra et al. 2015).

However, in Brazil, the soybean area is expected to increase by 9.7 million hectares over the next 10 years and reach, in 2025, 41.2 million hectares. It is the crop whose area is expected to expand the most in the next decade. Such expansion must occur mainly in areas of great production potential, such as those of *Cerrado*, in the region currently called MATOPIBA, for it comprises lands located in the states of Maranhão, Tocantins, Piauí, and Bahia. The area planted with grains in this region is expected to expand 18.7% over the next 10 years. This is equivalent to reaching the area of 8.7 million hectares, which, at its top limit, can reach 11.4 million hectares. Grain production in the states comprising this region is expected to increase from 19.4 million tons in 2014/2015 to 22.5 million in 2024/2025. At its top limit, production at the end of the period can reach 27.9 million tons of grain (MAPA 2015a, b).

Breeding Evolution in Brazil

Soybean breeding, developed by several public and private institutions, always seeking new and more productive varieties that are adapted to the Brazilian conditions, was and has been the one greatly responsible for the occupation and expansion of the soybeans in Brazil. Originated and domesticated from Northeast China, also known as Manchuria, soybeans arrived in Brazil in 1882, in the state of Bahia. This was the beginning of the process known as "tropicalization of soybeans in Brazil."

The following will describe the evolution of soybean breeding programs in each Brazilian state since its arrival in the country.

Rio Grande do Sul

The first reference of soybean introduction in Rio Grande do Sul is Minssen's (1901), which reports the planting of this legume before 1901, in the town of Dom Pedrito, by the agronomist A. Welhauser (Magalhães 1981).

As for soybean research, studies started in the state in the 1930s, in the former Colony Phytotechnical Experimental Station, in Veranópolis. This work gave rise

to the first soybean cultivar created in Rio Grande do Sul, called "Pioneira," which was launched in 1960 (Feres and Gomes 1981).

From 1946, research was extended to other experimental stations and also to the University of Rio Grande do Sul, which intensified its research program and established partnerships with the Agronomic Institute of Campinas (IAC) and the State Secretariat of Agriculture, with the introduction of collections from the Federal University of Viçosa (Sediyama et al. 2005).

In the 1950s, these institutions expanded their research by introducing a significant number of accessions from the USA, Japan, and various parts of Brazil (Feres and Gomes 1981). The purpose of the work at that time was to select soybean cultivars with high yield, plant height and insertion of the first pods suitable for mechanization of the crop, resistant to lodging and to the natural dehiscence of the pods, resistant to diseases and with good seed quality (Sediyama et al. 2005).

The result of this study was the gradual substitution of outdated cultivars such as Amarela Comum, Dorman, and Dortchsoy 67A by cultivars Serrana, Majos, Santa Rosa, Industrial, and Jubileu. These cultivars have contributed greatly to increase the average yield of Rio Grande do Sul crops (Miyasaka and Medina 1981).

In 1948, the Ministry of Agriculture began its research on soybean breeding in Rio Grande do Sul, in the city of Pelotas, at the *Instituto Agronômico do Sul* [Southern Agronomic Institute] (IAS), later called the *Instituto de Pesquisas Agropecuárias do Sul* [Southern Agricultural Research Institute] (IPEAS) (Sediyama et al. 2005). From 1953 to 1959, the program was limited to the introduction and evaluation of cultivars, and it was only after 1963 that the first hybridizations were performed (Feres and Gomes 1981).

Genetic material from the USA has always been the one to best adapt to the ecological conditions of southern Brazil. Thus, while hybridization and selection work was underway, farmers from Rio Grande do Sul used the best cultivars introduced from the USA, such as Hill, Hood, Majos, Bragg, Davis, Jew 45, Hampton, Hardee, and Bienville. The purposes of this program only began to be reached after 1968 when the cultivar Campos Gerais was launched (Feres and Gomes 1981).

Rio Grande do Sul is also marked as the state where the first transgenic soybean crops were grown on Brazilian soils. That fact took place in the 1998/1999 crop with the cultivation of RR soybeans, tolerant to Roundup herbicide, both developed by Monsanto.

Nonetheless, until that date, the commercial production of transgenic soybeans in Brazil was not allowed. Accordingly, due to the illegality of RR soybean farming, many crops in the state were incinerated and banned for 180 days (Lima 2005). In the 2000/2001 season, new clandestine RR soybean crops were found in the state. The first bags of RR soybeans to arrive in the state were smuggled from Argentina and became known to producers as "Maradona soybeans."

The definitive release of the farming of GMOs in Brazil occurred only in March 2005, with the approval of the Biosafety Law.

Santa Catarina

The first statistical data on soybeans in the state of Santa Catarina refer to 1951/1952 crop season, which was introduced by farmers who came from Rio Grande do Sul and started their activities in the West and in the Vale do Rio do Peixe (Doldatelli 1981).

The breeding work began in 1966/1967 and was coordinated by the *Instituto de Pesquisa Agropecuária do Sul* [Institute for Agricultural Research in the South] (IPEAS). The results allowed for the recommendation, in 1970, of cultivars with high yield and good agronomic traits such as Davis, Bragg, Hampton, Bienville, CNS-4, Hardee, Lee, and Santa Rosa, and this latter was for a long time the most cultivated in the state. After the establishment of the Santa Catarina company *Empresa Catarinense de Pesquisa Agropecuária S. A.* (EMPASC), the cultivars Paraná, Sulina, BR-1, and BR-3 were indicated (Orrego 1981).

Paraná

In the state of Paraná, soybean farming began in 1954, when about 2000 sacks were imported from São Paulo to be sown and soybean plants used as green manure in coffee plantations (Unfried and Braga 2011). However, until 1964 the cultivars used came mainly from Rio Grande do Sul and São Paulo (Kaster et al. 1981).

After 1965, due to the ease commercialization of soybeans, soybean research was implemented by the Ministry of Agriculture and the IRI Research Institute, and studies evaluated lines and cultivars provided by the IPEAS and the Federal University of Viçosa (UFV) (Unfried and Braga 2011).

From this program derived the cultivars Viçoja and Mineira, selected by the Federal University of Viçosa, as well as the launch of Campos Gerais, Paraná, Florida, and Sant'Ana. Moreover, the program allowed the recommendation of the American varieties Bragg, Davis, Hardee, Hill, and Hood and of Brazilian varieties Santa Rosa and Industrial (Sediyama et al. 2005).

In 1976, through an intergovernmental agreement, the *Centro Nacional de Pesquisa da Soja* [National Center for Soybean Research] (CNPSo) took over the coordination and development of soybean research in the state. The program developed by CNPSo gained national dimension and began to develop cultivars for the north, northeast, and central regions of Brazil (Unfried and Braga 2011). The program also contributed to the development of numerous cultivars such as Doko and later Doko RC, with significant cultivated areas in the *Cerrado* (Sediyama et al. 2015).

Among the soybean breeding programs that were developed in the state of Paraná, *FT-Pesquisa e Sementes*, founded by Francisco Terazawa, in the late 1960s, in Ponta Grossa, should be highlighted. It was the first Brazilian private company dedicated to soybean research and breeding. Cristalina was one of the first

cultivars that, in 1993/1994 crop season, was responsible for 52% of soybean production in Brazil (Sediyama et al. 2015).

One believes that the cultivar FT-Cristalina originates from a natural crossing between UFV-1 and an unknown parent. However, Hiromoto and Vello (1986) reported that the most probable genealogy of FT-Cristalina is Davis × UFV-1, due to the similarity between the parents.

According to Santini (2002), throughout the 1980s, its soybean cultivars began to predominate from the South to the Midwest of Brazil. In 1996, the soybean segment of *FT-Pesquisa e Sementes* was acquired by Monsanto, thus creating Monsoy.

Another important institution in soybean breeding in the state of Paraná is the *Cooperativa Central de Pesquisa Agrícola* [Central Cooperative for Agricultural Research] (COODETEC), created in 1995, which originated from the former research department in the 1970s, by the *Organização das Cooperativas do Estado do Paraná* [Organization of Cooperatives of the State of Paraná]—OCEPAR. COODETEC develops cultivars and licenses the protected materials to other partners that multiply the seeds. Due to the technological partnership agreement with Monsanto, COODETEC was allowed to launch six cultivars with the glyphosate-tolerant RR gene, including cultivar CD 219RR, one of the first GM cultivars, resistant to glyphosate, cultivated in Central Brazil (Cordeiro et al. 2007).

In 2014, all sectors of COODETEC were acquired by the American company Dow AgroSciences, a subsidiary of the Dow Chemical Company.

São Paulo

The first reports of soybeans in São Paulo date back to 1892, with experiments carried out by the Agronomic Institute of Campinas (IAC). However, its planting began to spread in the state from 1908, with the arrival of the first Japanese immigrants in the state, who used the legume as food (Sediyama et al. 2005).

Soybean breeding in São Paulo started in 1921, when Henrique Lobbe, director of the Experimental Station of São Simão-SP, introduced the varieties Hermann, Arksaben, Ebony, Biloxi, Guelph, Hato, Changai, Haberlandt, Hamilton, Easycook, Chiquita, and Hoosier. Subject to field conditions, the plants were selected among these materials, which resulted in three new cultivars, Jomichel, Julieta, and Joalo, very early, with development cycles close to 90 days, with very low plant structure. By means of crossings, the researcher also obtained another cultivar that received the name of Artrofi, which, although productive, also featured limited plant size (Miranda et al. 1981).

In 1936, Neme Abdo Neme, with the introduction of a new collection of materials from the USA and the Japanese colony based in Brazil, launched the cultivar Abura, for industry use, and Otootan, with black seeds used for fodder (Miranda et al. 1982).

With the introduction of materials from the Southern USA in 1951, José Gomes da Silva identified several promising materials for the state, including Acadian, Pelican, Improved Pelican, Yelnando, Volstate, N 46-2652, and D 49-772 (Miranda et al. 1982).

As early as 1952, a new breeding program was developed by Shiro Miyasaka under the guidance of Leonard F. Williams. This program gave rise to cultivars IAC-1, Santa Rosa, and Industrial. Later, by means of the hybridization between Yelnando and Aliança Preta, they obtained the cultivar IAC-2, which was one of the most cultivated in Central Brazil in the open regions of the *Cerrados* in the 1970s (Miranda et al. 1981).

In 1957, Shiro Miyasaka identified two cultivars less sensitive to the short days, Santa Maria-1 and Aliança Preta, which suggested the possibility of searching for cultivars that best adapted to the latitudes closer to the equator. This hypothesis inspired Romeu Afonso de Sousa Kiihl, a former IRI researcher, at IAC, in 1966, to undertake a postgraduate course at the University of the Mississippi under the guidance of researcher Edgar Hartwig. They decided to focus on a strategy line that would enable the expansion of soybeans in tropical regions, successfully implemented in the following decades (Unfried and Braga 2011).

The *Instituto Agronômico de Campinas* [Agronomic Institute of Campinas] (IAC), in 1967, received from Dr. Kirk L. Athow, hybrids he created at the Federal University of Viçosa, through crossings between Pelicano and IAC-2, with the Hardee variety. Romeu Kiihl worked with these populations and selected the line IAC 70-559 (IAC-4) (Miranda et al. 1982). Later, still in the IAC, Romeu Kiihl performed other hybridizations and backcrossings between American cultivars and PI 240.664 and launched cultivars with long juvenile period for floral induction, called IAC-6 and IAC-7 (Miranda et al. 1981).

According to Sediyama et al. (2005), other breeding programs were under development in the state of São Paulo, such as that of *Cooperativa de Produtores de Cana-de-Açúcar e Álcool do Estado de São Paulo* [São Paulo Sugarcane and Alcohol Producers Cooperative] (Coopersucar), the main purpose of which was to develop early varieties to allow the cultivation of two sugarcane plantations in the off-season, and that of the Higher School of Agriculture Luiz de Queiroz (ESALQ), which has emphasized, among other purposes, the development of cultivars suitable for human consumption.

Minas Gerais

The first references of soybeans in the state of Minas Gerais date back to 1930s, when it was studied at the old Experimental Substation of Lavras (Hunnicutt 1930).

More detailed studies on the behavior of cultivars were initiated in 1956/1957 crop season by Brandão (1961), at the Federal University of Viçosa (UFV). However, the beginning of soybean breeding in the state occurred in 1963, at

UFV, by means of the UFV/Purdue University (USA) Project, with Henry Shands as coordinator. At that time, a great number of varieties and lines of the South of the USA were introduced; however, most of the introductions did not show good adaptation, due to the sensitivity of the species to the length of the day (Sediyama 1981).

In 1965 the first hybridizations were performed by Kirk L. Athow, of Purdue University, with the collaboration of Marvin L. Swearingin and Elton R. da Silva and Tuneo Sediyama. This work gave rise to the first two cultivars developed in Minas Gerais, named Viçoja (Viçosa soybean) and Mineira, which derived from lines provided by Kuell Hinson of the Experimental Station of Gainesville, Florida (USA), and which had the variety Improved Pelican as common ancestor. These two cultivars occupied significant areas of the Triângulo Mineiro, São Paulo, Paraná, and Mato Grosso do Sul (Sediyama et al. 1983).

In 1968, the breeding program had the collaboration of Marvin L. Swearingin and, in the following years, also of Tuneo Sediyama, Carlo S. Sediyama, and Múcio S. Reis (Sediyama 1981).

In 1969, in an experimental field of Viçoja variety, Tuneo Sediyama selected a plant that had superior traits to those of that variety, mainly because it features a longer cycle, higher plant height, and higher height of the first pod. All other traits were similar to those of Viçoja. Due to the lack of knowledge regarding its pedigree and the absence of segregation in later generations, which indicated that it did not result from a natural crossing, and as there was no other line or variety with similar traits in that locality, Viçoja was believed to be a mutation. Thus, it was first called "Viçoja mutante," and later, in 1973, it was as a variety under the name of UFV-1 (Sediyama 1981).

UFV-1 was extensively cultivated in the 1970s to 1980s, mainly in the Cerrado of Minas Gerais, Goiás, Mato Grosso do Sul, and Mato Grosso and, to a lesser extent, in the states of São Paulo and Paraná (Sediyama et al. 2015).

Up to 2015, during this program, 53 adapted cultivars were developed, mainly to the edaphoclimatic conditions of the southeast and Midwest regions of Brazil. Since 2013, the program has been led by Felipe Lopes da Silva, with the collaboration of Tuneo Sediyama and Carlos S. Sediyama.

Another ongoing program at the Federal University of Viçosa is that of molecular genetics in soybean breeding for the agroindustry (Moreira et al. 1995). Through this program, in collaboration with the researchers of the Department of Phytotechnology of the UFV, the first cultivars with traits more suitable for human consumption, with the removal of lipoxygenases (Lox 1, Lox 2 and Lox 3), were developed. The cultivars were named UFVTN 101, UFVTN 102, UFVTN 103, and UFVTN 104.

In 1988, the *Fundação Triângulo de Pesquisa e Desenvolvimento* was established. Among the several cultivars developed by the institution, the one that stood out the most was MG/BR 46 Conquista, which was launched in 1995, and became one of the most cultivated in Central Brazil (Sediyama et al. 2015).

Cooperativa Agropecuária do Alto Paranaíba Ltda-Coopadap, founded in 1994, in São Gotardo, MG, is another important institution in soybean breeding

in the state (Sediyama et al. 2005). Among the several cultivars developed by this program, which are mainly intended for the oil and meal industry, the CAC-1 stands out.

In 1997, under the leadership of Osvaldo Toshiyuki Hamawaki, the Federal University of Uberlândia (UFU) started a breeding program aimed at developing new conventional cultivars that were productive, resistant to biotic and abiotic stresses, and featured high phenotypic adaptability and stability. The first cultivars launched were named UFUS Impacta and UFUS Milionária (UFU 2010).

Goiás

The introduction of soybeans in the state of Goiás occurred in 1950, by Znamenskiy (1965), who conducted experiments with the crop for 15 years.

In 1969, the Secretariat of Agriculture began the tests for evaluation of cultivars in partnership with institutions of other states. Among the materials evaluated, varieties Santa Rosa, Viçoja, Mineira, Hardee, and IAC-2 (Santos and Costa 1981) stood out. However, it was only in the 1973/1974 crop season that the breeding program in the state started by means of hybridization, when the cultivar Jupiter was crossed with the variety IAC-2, originating cultivars with the prefix GO (Costa et al. 1981).

The contribution of the *Centro de Pesquisa Agropecuária do Cerrado* [Center for Agricultural Research] (SPA), with the participation of the CNPSo, as well as of the *Empresa Goiânia de Pesquisa Agropecuária* [Goiânia Agricultural Research Company] (EMGOPA), universities, and the private initiative, should be highlighted in the program conducted in Goiás. Cooperative System of Agricultural Research (SCPA). Among the factors that considerably accelerate the development of new cultivars in the state, the possibility of producing two crops per year should be pointed out, as the region does not present frost problems (Spehar et al. 1993).

This program gave rise to the varieties Doko, Numbaira, BR-9 (Savana), and EMGOPA. Moreover, several varieties were developed for the region near the equator, which effectively consolidated soybean adaptation in the states of Maranhão and Piauí. Among these cultivars, we highlight BRS Tracajá, BRS Sambaíba, BRS Carnaúba, BRS Barreiras, and BRS Babaçu (Sediyama et al. 2015).

It should be noted that the first cultivar selected in Goiás was FT-Cristalina, which resulted from a selection made by Francisco Terasawa, in a field of the cultivar UFV-1, in Londrina, PR, at Serrana Farm, during the winter of 1972. Initially, the derived line was identified as M-4 and tested in the municipality of Unaí, MG. In 1974, the line was evaluated for 2 years at Vereda Farm, in Cristalina, GO. After this period, M-4 started to be called Cristalina, in homage to the municipality in which its evaluations were conducted (Terazawa and Silva 1981).

Mato Grosso

In the state of Mato Grosso, the challenges for the implementation of the soybean crop were greater, due to the territorial extension of the state, the high initial crop implementation costs, and the inexistence of production infrastructure and market logistics for transportation of the crop (Unfried and Braga 2011).

The first commercial plantation initiatives in the state date back to the early 1970s, with cultivation, mainly, of cultivars IAC-2, UFV-1, and Santa Rosa, in areas ranging from 5 to 100 ha (Paro and Santos 1981). In association with soybean producers in 1981, EMATER, CPAC, and UFV developed the first cultivar especially for Mato Grosso, which was called UFV-Araguaia and derived from the crossing between Hardee and IAC-2 (Sediyama et al. 1981).

In 1993, the Foundation for Support to Agricultural Research of Mato Grosso, *Fundação MT*, formed by 23 farmers was established and had researcher Dario Minoru Hiromoto as president. The first cultivars developed include MT/BRS Xingu, BRSMT Uirapuru, BRSMT Pintado, FMT Tabarana, and FMT Tucunaré (Sediyama et al. 2015).

In 2001, *Fundação MT* and *Tropical Melhoramento Genético* (TMG), established by researcher Romeu Afonso de Sousa Kiihl, started a partnership dedicated to the development of soybean cultivars. The headquarter of TMG is in Cambé, PR. Annually, about 45,000 progenies are evaluated, and the first cultivars were launched in 2005. In 9 years of research, 24 soybean cultivars were developed. TMG was the first company to introduce Inox technology, which confers resistance to Asian rust (*Phakopsora pachyrhizi* Syd. e P. Syd), with cultivars TMG 801 and TMG 803 (Fundação MT 2011).

Maranhão, Piauí, Tocantins, and Bahia (MAPITOBA—MATOPIBA)

The acronym MAPITOBA or MATOPIBA, formed by the initials of the states of Maranhão, Piauí, Tocantins, and Bahia, refers to the new frontier of occupation of soybeans in the Brazilian Cerrado.

In this region, soybean research began in 1968 in the region of Irecê, BA (Sediyama et al., 2005). However, in the following decades, little was done for the development of cultivars adapted to this area. Most of the work was limited to the introduction and selection of cultivars and lines developed in research centers in regions where soybean farming was already consolidated.

However, since the mid-1990s, with the increase in agricultural activity in the region, several companies started to indicate cultivars for the region such as Monsanto, TMG, Brasmax, Pioneer, Soy Tech Seeds, and Donmario. The performance of *Fundação de Apoio à Pesquisa do Corredor de Exportação Norte* [Foundation for Support to the Research of the Northern Export Corridor]

(FAPCEN), which, in partnership with Embrapa, has developed specific cultivars for this region, should also be highlighted.

Multinationals in Soybean Breeding

Until the 1980s, national public and private companies were still responsible, in a hegemonic way, for the creation and transfer of technology and for the seed supply to the entire domestic soybean market. However, in the 1990s, the globalization process significantly affected the agricultural sector. Moreover, in the same decade, with neoliberal political guidelines, the current government chose to remove public power from the productive sphere of the economy, which gave rise to the depression of public research institutions. As a result new players emerged, identified as large international capital corporations (Unfried and Braga 2011).

In addition to the aforementioned facts, the enactment of the Plant Variety Law (Law No. 9456/1997), which allows the financial return to companies for the creation of new varieties, and Law 10.814/2003, which approved the commercial release of GMOs, has made the market for cultivar development more conducive to the setting up of multinationals.

In 1996, Monsanto began its soybean breeding activities in Brazil, first with conventional cultivars, and, as of 2005, it modified its genetic base to GM cultivars. Later, other companies such as Pioneer, Syngenta, Basf, Bayer, and Dow also implemented their soybean breeding programs (Sediyama et al. 2015).

According to Unfried and Braga (2011), all such institutional structure triggered a process of acquisitions and mergers of companies in the field of seeds, fertilizers, and other inputs. The main acquisitions of companies associated with the soybean market, which occurred in Brazil or that have had a negative impact on the domestic market, are depicted in Table 1.1.

Many of these companies, due to the market power of soybeans in Brazil, now the second largest producer in the world, and the possibility of aggregating revenues from royalties, have been making investments in the biotechnology sector for the development of GM traits. According to Sediyama et al. (2015), in 2011 alone, about 85% of all Brazilian production came from soybean with the trait RR, glyphosate-tolerance technology developed by Monsanto.

Table 1.2 lists some of the technologies already approved for use in soybeans in Brazil and some that are still in the test phase.

Final Remarks

The current production and productivity level of soybeans in Brazil, as well as the crop occupation in regions previously unsuitable for growing the legume, is due to several factors such as the development of production and management technology

Table 1.1 Main acquisitions of companies associated with the soybean market that impacted the Brazilian market up to the year 2015

Year	Company acquiring	Origin	Acquisition	Origin
1996	Monsanto	USA	FT—Pesquisa e Sementes (creating Monsoy)	Brazil
1998	Dow	USA	Mycogen	USA
1998	Monsanto	USA	Braskalb Agropecuária Brasileira Ltda., Dekalb's representative	Brazil
1998	Monsanto	USA	Divisão internacional de sementes da Cargill na América Latina	Brazil
1999	Du Pont	USA	Pioneer Sementes do Brasil	Brazil
1999	Agrevo	Germany	Sementes Ribeiral	Brazil
1999	Du Pont	USA	Dois Marcos	Brazil
2000	Syngenta	Switzerland	Novartis + Astra Zeneca	Switzerland
2000	Aventis	France	Agrevo	Germany
2002	Bayer CropScience	Germany	Aventis	France +
2002	Nidera	Netherlands	Aventis (Agrevo + Rhone Poulenc)	Germany
2005	Nidera	Netherlands	Bayer CropScience (corn and soybean division)	France +
2014	Dow AgroSciences	USA	COODETEC	Germany

Source: Adapted by the authors

Table 1.2 GM technologies developed for soybeans by the main companies operating in the Brazilian market

Technology	Action	Developer company	Year of approval in Brazil
Roundup Read® (RR1)	Tolerance to glyphosate herbicide	Monsanto	1998
Cultivance®	Tolerance to the herbicides of imidazolinone group	Embrapa and BASF	2009
Liberty Link™	Tolerance to glufosinate-ammonium herbicide	Bayer CropScience	2010
Intacta RR2 PRO®	Resistance to caterpillars and tolerance to glyphosate herbicide	Monsanto	2010
Enlist E3®	Tolerant to herbicides glyphosate, glufosinate-ammonium and 2,4-D	Dow AgroSciences	2015
		MS Technologies	
Dicamba	Tolerant to dicamba herbicide	Monsanto	–
HPPD	Tolerant to herbicides that inhibit 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme	Syngenta e Bayer CropScience	–

Source: Adapted from Fundação MT (2014) and CBI (2015)

and also breeding, with the development of varieties that are more productive, adapted to the farming conditions and resistant to the main diseases.

The evolution of soybean breeding in Brazil occurred in two periods. The first occurred from the introduction of soybeans in the country until the 1980s. In this stage, the public sector was responsible for the development of varieties, seed supply, and technology transfer. In the period, important research centers were created, mainly in the states of Rio Grande do Sul, São Paulo, and Minas Gerais, where it was possible to adapt soybeans to the conditions of the Cerrado and regions of low latitudes, as well as the development of varieties resistant to various diseases.

After the 1990s, with the globalization and enactment of the Plant Protection Law and due to the position of the then current government, a new era for the improvement of soybeans in Brazil began, marked by the participation of large corporations with international capital such as Monsanto, Pioneer, Syngenta, Basf, Bayer, Dow, and others that, in addition to the development of adapted and productive varieties, have sought genotypes of greater market value from biotechnology, with the introduction of GM traits, for instance.

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