The Evolution of Science in a Latin-American Country: Genetics and Genomics in Brazil

Francisco M. Salzano[1]
Genetics Department, Biosciences Institute, Federal University of Rio Grande do Sul, Porto Alegre, 91501-970, Brazil
ORCID ID: 0000-0002-4753-3184 (F.M.S.)

ABSTRACT This article begins with a brief overview of the history of Brazil and that of Brazilian science, from the European discovery of the country in 1500 up to the early 21st century. The history of the fields of genetics and genomics, from the 1930s, is then first examined from the focal point of the lives and publications of the three persons who are generally considered to be the founders of genetics in Brazil (C. A. Krug, F. G. Brieger, and A. Dreyfus), and then by 12 other researchers up to 1999. The area of molecular genetics and genomics from 2000 to present is then described. Despite the problems of underdevelopment and the periodical political and economic crises that have affected life in Brazil, the fields of genetics and genomics in Brazil can be regarded as having developed at an appropriate pace, and have contributed in several major ways to world science.

KEYWORDS science history; genetics/genomics in Brazil; plant genetics/genomics; animal genetics/genomics; human genetics/genomics; molecular genetics/genomics

CERTAIN conditions need to be met for science to develop within a country. Crucial factors include, of course, having the right people present at the right places and the appropriate times. Their full potential cannot emerge, however, if a series of environmental conditions do not also occur. These include: (a) reasonably steady and adequate financial funding; (b) a good interchange between basic and applied research; (c) appropriate political conditions (peace and liberty); (d) due public consideration for the role of science in everyday life; and (e) in recent times, appropriate access to international networks of research support and interchange. Science is intimately related to economic development and a question that was often posed in the 20th century was whether good science can be performed in relatively poor and geographically peripheral countries outside of North America and Europe, such as Brazil. The answer, fortunately, is "yes," if the conditions listed above occur. This article presents the case of Brazil as an example, showing how science, and in particular the fields of genetics and genomics, have developed there over a period of >80 years.

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[1]Address for correspondence: Departamento de Genética, Instituto de Biociências, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500 (Caixa Postal 15053), 91501-970 Porto Alegre, RS, Brazil. E-mail: francisco.salzano@ufrgs.br

Science and Development in Brazil

The history of political and economic development begins with the European "discovery" of Brazil in 1500 that was followed by a colonial period under the control of Portugal, which lasted three centuries. That period can be characterized as one of external dependence, latifundium properties (mainly sugar plantations in the northeast and cattle raising in the south), and an economy that relied heavily on slavery. Of course, these conditions were not favorable to science or education. To give an example, the first school in the country was founded only in 1549 in Bahia, and for much of the colonial period, much of the population received little or no education.

This situation was greatly modified by the transference of the Portuguese Court to Brazil due to Napoleon's invasion of Portugal. During the ensuing 125 years, Brazil underwent many political changes. It reached the status of Vice-Kingdom in 1815, then achieved independence as an Empire in 1822, and finally as a Republic in 1889. During this period, many institutions that became dedicated to research were founded, such as the National Museum in Rio de Janeiro (1818), the Agronomic Institute of Campinas (IAC) (1887), the Luiz de

Table 1 Some landmarks, at the institutional level, related to science and development in Brazil and, more specifically, with genetics/genomics

Year	Event
1934	Foundation of the University of São Paulo, with a decided focus in science.
1951	Foundation of the National Research Council (Conselho Nacional de Pesquisa, CNPq) and the Coordination for the Higher Training of University Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES).
1955	Foundation of the SBG (Sociedade Brasileira de Genética).
1960	Creation of São Paulo's Foundation for Research Aid (FAPESP), soon followed by similar institutions in the different states of Brazil.
1973	Foundation of the Brazilian Company of Agricultural Research (EMBRAPA).
1978	Foundation of the Brazilian Journal of Genetics (Revista Brasileira de Genética).

Queiroz School of Agriculture in Piracicaba (1901), and the Oswaldo Cruz Institute in Rio de Janeiro (1907). The Brazilian Academy of Sciences was founded in 1916, and the Ministry of Education and Health was founded in 1930.

The foundation of the University of São Paulo in 1934 was a particularly important landmark in the development of Brazilian science due to its dedicated focus on research. Other important events at the institutional level that furthered Brazilian science are listed in Table 1. Not least, several funding agencies were created, beginning in 1951, and the Brazilian Society of Genetics (SBG) was founded in 1955. This institution has played a key role in the coordination and dissemination of genetics and genomic research at the national and international levels. Its 63rd congress was held in 2017 and had an attendance of >1000 geneticists. SBG was also responsible for the creation of the *Brazilian Journal of Genetics* in 1978, which adapted its name to *Genetics and Molecular Biology* in 1998 in recognition of the increasing number of non-Brazilian authors in its pages. Volume 40 was edited in 2017 and featured a large number of excellent research contributions.

Some figures will illustrate the state of Brazilian science. In 2006, 422 institutions developed scientific projects involving 20,797 research groups and 211,000 researchers, the number of researchers per 1000 persons being 0.88. In 2008/2009 a total of 32,100 indexed research articles were published, which amounts to 2.69% of the world production (Salzano 2012). That is a substantial figure, but Brazilian scientific periodicals are still at a disadvantage in relation to world periodicals in general. In 2016, despite the fact that 82% of them have open access (against a world average of 18%), only 5 of 122 journals had an impact factor (IF) >2. One of them (Memórias do Instituto Oswaldo Cruz) publishes articles in the areas of microbial genetics and genomics and had an IF of 2.6 (Marques 2017).

Global evaluations of Brazilian science have been published at regular intervals, but the great majority are in Portuguese which limits their readership. Salzano (2012) listed a total of 29 books and documents, issued between 1978 and 2008. In 2002, however, a book published in English evaluated this area in a comprehensive way (Campos de Carvalho *et al.* 2002).

Figure 1 The holy trinity who were considered to be the founders of Brazilian Genetics, from left to right: Carlos A. Krug, Friedrich G. Brieger, and André Dreyfus.

Genetics and Genomics in Brazil

Introduction

In what follows, I will try to give an accurate characterization of this area of research in my country. The focus in this description will be on several key persons involved and their specific fields of research within genetics or genomics. The methodological advances in these two linked areas can only be characterized as astonishing, and range from the simple macroscopic description of breeding experiments to the sophisticated use of microscopic, biochemical, molecular, and bioinformatic tools.

The founders

We are now in a position to consider the beginnings of genetics in Brazil, starting with "the right persons in the right places and times." In this case, these individuals were what has been called the "holy trinity" (Figure 1): Carlos A. Krug, Friedrich G. Brieger, and André Dreyfus. Not surprisingly, Brieger and Dreyfus were affiliated with the University of São Paulo, and Krug to a research institution of that state.

C. A. Krug (1906–1973) was basically an applied geneticist, mainly concerned with the improvement of the different kinds of plants grown in the IAC, in the state of São Paulo. At age 25, he received a fellowship from São Paulo's Agriculture Secretary to specialize in genetics and cytology at Cornell University, and in 1934 he obtained a Ph.D. in Brazil from the studies performed there in maize. In 1933, he had started research in coffee, which was the main crop studied at IAC for decades. Most of the studies he performed were described in Portuguese, in the technical bulletin of the institution. In 1940, he summarized the cytological observations (Krug and Mendes 1940) and, in 1951, the genetics of the genus *Coffea* (Krug and Carvalho 1951) in international journals. His main contribution to Brazilian science was the formation of an extensive team of researchers at IAC, who were responsible for the improvement of coffee, maize, beans, cotton, and rice. One of the main contributions of this group was the

Figure 2 Theodosius Dobzhansky doing field work in Rio Grande do Sul in 1956. From left to right: Antonio R. Cordeiro, the founder of the Porto Alegre genetics group; Francisco M. Salzano; Danko Brncic, an important Chilean geneticist; and Luiz Glock, an undergraduate student at the time who later developed a successful career in biostatistics.

development of *Coffea* lineages resistant to the *Hemileia vastratix* rust disease that plagued the crop in Africa, before its introduction in Brazil. In later years, Krug assumed administrative tasks, especially at the United Nations Food and Agriculture Organization.

Friedrich G. Brieger (1900–1985) was born and made his first academic studies (including his Ph.D.) in Germany. He was Jewish, however, and with the intensification of anti-Jewish discrimination and persecution in that country, he migrated first to England and then to Brazil. In 1936, he had been invited to create the Chair of Cytology and General Genetics at the Agricultural School Luiz de Queiroz in Piracicaba, state of São Paulo, that had been incorporated into the University of São Paulo in that year. At this institution he was responsible for the organization of an extensive group of brilliant geneticists. The Chair was transformed into an Institute in 1958 and, over many years, the group developed extensive programs in crop improvement, including maize, vegetables, fruits, sugarcane, foraging grasses, and microorganisms. However, in contrast to Krug—whose interests were solely in applied studies, Brieger was also interested in basic genetic and evolutionary studies, particularly the indigenous races of maize and orchid phylogeny. A selected list of his non-Portuguese articles are as follows: Brieger (1937, 1938, 1950, 1955) and Brieger *et al.* (1958). He was also particularly concerned with international collaboration, and what were considered to be the first three congresses of Brazilian genetics (the "Weeks of Genetics" in 1943, 1949, and 1956) were organized by him and held in Piracicaba.

In later years, however, Brieger was increasingly involved with bureaucratic matters and he collaborated with the military dictatorship then ruling in Brazil; activities that were strongly criticized by the genetics community. He finally returned to Germany, where he spent the last years of his life.

André Dreyfus (1898–1952) was born in Pelotas, Rio Grande do Sul and studied medicine in Rio de Janeiro, obtaining his degree in 1919. But he soon became interested

Figure 3 Crodowaldo Pavan, a key person in the development of genetics in Brazil.

in the problems of cytology, histology, and biology in general. He was one of the first to teach a private course in genetics, and in 1934 was invited, with other distinguished scholars, to found the University of São Paulo and its School of Philosophy, Sciences and Letters. In this School he became the first professor in its Biology Chair. The thesis that resulted in this title was about the chromosome cycle and sex determination of *Rhabdias fueleborni*, an amphibian parasite (Dreyfus 1937). In the early years of the following decade, he was approached by Dr. Harry M. Miller, then Director for Natural Sciences of the Rockefeller Foundation (see below), to stay in the US for an extended period of time to become acquainted with the genetics work which was being conducted there. However, he suggested an alternative: that the Rockefeller Foundation finance a distinguished North American geneticist to come to Brazil and start a common research project with Brazilians. Miller invited Theodosius Dobzhansky to be this person and this was especially fortunate as it began a collaboration between Dobzhansky and numerous Brazilians that would last for decades.

Several articles were published in Portuguese by Dreyfus and his co-workers in the 1940s and 1950s. In 1952, he was still working in his department up to 2 hr before suffering a brain hemorrhage and dying. In a tribute to him made by the Brazilian Society for the Advancement of Science, Dobzhansky stressed many aspects of Dreyfus' personality: his vision for the importance of specific fields of research, openness to accept and help young collaborators, and the strong positions he would take against antiscience

Table 2 Main investigations and the people involved with them in the early history of genetics in Brazil (1933–1961)

Place	First studies	Main investigations	Principal investigators
Agronomic Institute, Campinas, São Paulo	1933	Genetics and improvement, maize, beans, cotton, rice, and coffee	C. A. Krug, A. Carvalho, A. J. T. Mendes, and D. M. Medina
Luiz de Queiroz School of Agronomy, Piracicaba, São Paulo	1936	Phylogeny in tropical species, orchid cytology, genetics and improvement, maize, bee, and scorpion cytogenetics and genetics	F. G. Brieger, S. T. Piza, J. T. A. Gurgel, A. Blumenschein, W. E. Kerr, E. Paterniani, and R. Vencovsky
University of São Paulo, São Paulo	1937	Ecology, systematics, cytology, population genetics, effects of ionizing radiation, in *Drosophila* Cytology, and physiology, in *Rhynchosciara* Medical and human population genetics	A. Dreyfus, C. Pavan, A. Brito da Cunha, O. Frota-Pessoa, L. E. Magalhães, and P.H. Saldanha
Federal University of Minas Gerais, Belo Horizonte, Minas Gerais	1940	Quantitative cytology, cytogenetics, *Triatoma*, *Anopheles*, *Bothrops*, *Crotalus*, and *Australorbis* cytology	G. Schreiber
Federal University of Rio de Janeiro, Rio de Janeiro	1945	Taxonomy, cytogenetics, maternal inheritance, population genetics, in *Drosophila*	A. G. L. Cavalcanti and C. Malogolowkin
UFRGS, Porto Alegre, Rio Grande do Sul	1949	Taxonomy, ecology, cytogenetics biophysical/biochemical genetics, population genetics, ionizing radiation effects, *Drosophila*, human population, and medical genetics	A. R. Cordeiro, F. M. Salzano, C. V. Tondo, F. Lewgoy, H. Winge, M. Napp, and E. K. Marques
Federal University of Bahia, Salvador, Bahia	1954	Blood groups, sickle cell anemia, in humans	C. M. Pedreira
State University of São Paulo, Rio Claro, São Paulo	1959	Genetics, evolution, bees, blood groups, birds, genetics and improvement, in *Eucalyptus*	W. E. Kerr, A. Buschinelli, and C. C. Cruz
UFPR, Curitiba, Paraná	1959	Genetics and population genetics, *Drosophila*, inbreeding, isolates, effects of ionizing radiation, humans, and medical genetics and genetic counseling	N. Freire-Maia, A. Freire-Maia, A. Quelce-Salgado, F. A. Marçallo, and H. Krieger

Source: Da Cunha *et al.* (1961).

views. Dreyfus was primarily a scholar of the old type, with a deep interest not only in science, but also in history and the arts.

The appropriate funding essential for nascent research teams was provided especially by the Rockefeller Foundation. Its role in these early days cannot be overemphasized, and this was especially due to its Director for Natural Sciences, Harry M. Miller Jr. (born 1895). As already mentioned, it was Miller who invited Theodosius Dobzhansky (1900–1975; Figure 2)—the fourth person generally considered responsible for the birth of Brazilian genetics—to come to Brazil. Here Dobzhansky played a key role in the formation of an excellent team of geneticists. He started his work with *Drosophila* at the University of São Paulo in 1943, working with Crodowaldo Pavan (Figure 3), who was another researcher fundamental to the early work in Brazilian genetics (described further below).

Early history (1933–1961)

Some of the main investigations performed in this period are summarized in Table 2. In 1961, 28 years after the beginning of Krug's studies, good research was being performed at nine centers, spread all over the country from Bahia to Rio Grande do Sul. In the academic field, the studies with *Drosophila* were extended to orchids, *Rhynchosciara*, other insects, vertebrates, and humans; while in applied genetics—besides the research in coffee, breeding programs in maize, beans, cotton, rice, *Eucalyptus*, and bees should be mentioned. These projects were performed under the leadership of the 36 persons listed, although, of course, many others have also contributed.

Consolidation (1962–1999)

Subsequent developments in genetics, including the beginnings of genomics, were enormous and the task of reviewing them adequately is thus difficult. Therefore, to provide an idea of the investigations performed in this period, I have singled out three distinguished researchers and their work in each of the following areas: animal, micro-organism, plant, and human genetics. Of course, my choices are personal ones and my colleagues might well consider that other persons should have been chosen.

Undoubtedly the most influential researcher of what could be considered the second generation of Brazilian geneticists was Crodowaldo Pavan (1919–2009). He not only contributed directly in a significant way to genetics, but also formed a first-class team of researchers and coordinated a series of joint efforts by scientists all over Brazil in the investigation of key problems in the field. From the very beginning, in 1943, he was crucial in bringing Dobzhansky into Brazilian genetics, initially with the description of Brazilian species of *Drosophila*. Besides this important collaboration, he discovered

Figure 4 From left to right: Sérgio Olavo Pinto da Costa, Darcy Fontoura de Almeida, and João Lúcio de Azevedo; another triad of geneticists mainly responsible for the development of the genetics of micro-organisms in Brazil.

the giant chromosomes of *Rhynchosciara angelae* and was the first to identify DNA synthesis in its puffs. In 1964, he accepted a position to organize a cell laboratory in Oak Ridge, TN, and in 1968 he became a full professor at the University of Texas. Although he returned to Brazil in 1975, during his 11-year stay in the US he had established a vigorous program of US–Brazilian interchange. He then became especially interested in various insects that plagued different types of crops and shifted his research emphasis accordingly. Besides his direct contribution to science, he occupied important positions in institutions related to the defense and support of science. A few of his important publications are Breuer and Pavan (1955), Pavan and Basile (1964, 1966), and Lee and Pavan (1974).

The second person that should be mentioned in the field of animal genetics is Warwick E. Kerr. He obtained his Ph.D. under the mentorship of F. G. Brieger in 1948, working with *Melipona*, a bee genus, and maintained this interest in bee genetics throughout his academic career. After obtaining his degree, he was admitted to the staff of the Luiz de Queiroz School in Piracicaba, but in the following years he moved successively to the State University of São Paulo in Rio Claro, University of São Paulo–Ribeirão Preto School of Medicine, Instituto Nacional de Pesquisas da Amazônia, Federal University of Maranhão, and Federal University of Uberlândia. He also played a key role in the administration of research funds and in the defense of Brazilian biodiversity. A large number of his articles were published in Portuguese, but his contribution to the analysis of sex determination in bees (Kerr 1997) was written in English and is a valuable piece of research.

Antonio Brito da Cunha had an academic career that closely paralleled that of C. Pavan, and they were close friends. His Ph. D. was obtained in 1943, and in 1951 he worked with Dobzhansky at Columbia University for 1 year. Some years later, he was a visiting professor at the University of Texas in Austin. His initial work was in the description and dynamics of chromosome inversions in *Drosophila*, but in later years he became interested in the effects of virus infections in insects. Two selected aspects of this work are featured in the articles by Da Cunha *et al.* (1968) and Stoltz *et al.* (1973).

Table 3 Selected information about genome studies performed in Brazil or with Brazilian participation

	Taxonomic details
1.	**Superkingdom:** Prokaryotes
1.1.	**Kingdom:** Prokariotae
1.1.1.	**Subkingdom:** Bacteria
1.1.1.1.	**Species:** *Chromobacterium violaceum*, *Gluconacetobacter diazotrophicus*, *Herbaspirillum seropedicae*, *Leifsonia xyli*, *Leptospira interrogans*, *Mycoplasma hyopneumoniae*, *M. synoviae*, *Rhizobium tropici*, *Xanthomonas axonopodis*, *X. campestris*, and *X. fastidiosa*
2.	**Superkingdom:** Eukaryotes
2.1.	**Kingdom:** Protoctista
2.1.1.	**Species:** *Leishmania chagasi* and *Trypanosoma cruzi*
2.2.	**Kingdom:** Fungi
2.2.1.	**Species:** *Crinipellis perniciosa* and *Paracoccidioides brasiliensis*
2.3.	**Kingdom:** Plantae
2.3.1.	**Species:** *Coffea arabica*, *Eucalyptus grandis*, *Paullinia cupana*, *Saccharum officinalis*, *Arachis duranensis*, and *A. ipaensis*
2.4.	**Kingdom:** Animalia
2.4.1.	**Species:** *S. mansoni*, *Necator americanus*, *Litopenaeus vannamei*, *Rhodnius prolixus*, *Apis mellifera*, *A. florea*, *Melipona quadrifasciata*, *Bombus terrestris*, *B. impatiens*, *Lasioglossum albipes*, *Eufriesea mexicana*, *Megachile rotundata*, *Dufourea novaeangliae*, *Habropoda laboriosa*, *Anopheles darlingi*, *Drosophila sechellia*, *D. simulans*, *D. yakuba*, *D. erecta*, *D. ananassae*, *D. persimilis*, *D. willistoni*, *D. mojavensis*, *D. virilis*, *D. grimshawi*, *Latimeria chalumnae*, *Bos taurus*, and *Homo sapiens*

Source: Salzano (2005) with additions. The Brazilian initiatives involved 23 consortia, identified, with a list of 31 references, in the indicated reference.

The field of the genetics of micro-organisms that developed in Brazil was especially due to a new triad of workers: Darcy Fontoura de Almeida, João Lúcio de Azevedo, and Sérgio Olavo Pinto da Costa (Figure 4). D. F. Almeida graduated in medicine in 1954, and in 1958 was admitted to the staff of the Biophysics Institute at the Federal University of Rio de Janeiro, where he remained for the rest of his life. His early work was with *Escherichia coli*, but afterward he became interested in DNA structure and bioinformatics, closely collaborating with Ana Tereza de Vasconcelos in several genomic studies. Selected articles by him from this period are Alves *et al.* (1998a,b) and Vasconcelos *et al.* (2000).

João Lúcio de Azevedo has had an important role in the establishment of micro-organism genetics laboratories throughout Brazil. His early work in this area was stimulated by Brieger in Piracicaba, and afterward (1971) he obtained a Ph.D. from Manchester University, UK. He is a prolific author and on September 27, 2017, the number of citations of his articles on the Scopus database was 3129, with $h = 28$. Selected articles by him and co-workers from this period are Barcellos *et al.* (1998), Nascimento *et al.* (1999), and Pereira *et al.* (1999).

Table 4 Selected list of molecular genetics/genomics research that is presently being carried out in Brazil, with an indication of their main contributors

Place	Institution	Research	Principal investigators[a]
Belém, Pará	Federal University of Pará	Mitochondrial, Y-chromosome, and autosome variability in a variety of organisms, especially fishes, New World Primates, and humans	A. K. C. Ribeiro-dos-Santos, C. Y. Nagamachi, E. J. M. Santos, H. Schneider, I. Schneider, I. Sampaio, J. C. Pieczarka, J. F. Guerreiro, M. P. C. Schneider, and S. E. B. Santos
Recife, Pernambuco	Federal University of Pernambuco	Several aspects of general cytology and cytogenetics (mainly plants)	M. Guerra
Salvador, Bahia	Federal University of Bahia	Molecular evolution	V. R. Paixão-Côrtes
Brasília, Distrito Federal	Catholic University of Brasília	Plant and human variability	D. Grattapaglia
	University of Brasília	Human variability	S. F. Oliveira
Belo Horizonte, Minas Gerais	Federal University of Minas Gerais	Molecular animal and human variability	E. Tarazona-Santos, F. R. Santos, and S. D. J. Pena
Petrópolis, Rio de Janeiro	National Laboratory of Synchroton Light	Genomics of different organisms	A. T. R. Vasconcelos
Rio de Janeiro	Federal University of Rio de Janeiro	Molecular variability in humans and other organisms	A. B. Carvalho, A. M. Solé-Cava, C. Russo, M. Alves-Ferreira, and R. Moura-Neto
	State University of Rio de Janeiro	Human variability	L. Gusmão
	Oswaldo Cruz Foundation	Human variability	P. H. Cabello
São José do Rio Preto, São Paulo	State University of São Paulo	*Drosophila* variability	C. M. A. Carareto
Ribeirão Preto, São Paulo	University of São Paulo	Genomics of different organisms, especially bees	A. L. Simões, K. Hartfelder, W. A. Silva Jr., and Z. L. P. Simões
São Carlos, São Paulo	Federal University of São Carlos	Molecular variability in different organisms	F. M. F. Nunes and P. M. Galetti Jr.
Rio Claro, São Paulo	State University of São Paulo	Plant evolution	C. P. Silva
Campinas, São Paulo	State University of Campinas	Molecular variability in plants and *Drosophila*	A. P. Souza and L. B. Klaczko
Botucatu, São Paulo	State University of São Paulo	Cytogenetic and molecular variability in fishes	F. Foresti
São Paulo	University of São Paulo	Evolutionary aspects of the molecular variability in a wide range of organisms	C. Y. Miyaki, D. Meyer, C. F. M. Menck, G. Marroig, M-A. von Sluys, P. A. Otto, T. Hünemeier, and W. A. Neves
Curitiba, Paraná	UFPR	Molecular immunological variability	M. L. Petzl-Erler
	Oswaldo Cruz Institute	Molecular variability in micro-organisms	S. Goldenberg
Florianópolis, Santa Catarina	Federal University of Santa Catarina	Human variability	I. R. Souza
Santa Maria, Rio Grande do Sul	Federal University of Santa Maria	Molecular variability in *Drosophila*	E. L. S. Loreto
Porto Alegre, Rio Grande do Sul	UFRGS	Evolutionary molecular aspects of a wide variety of organisms, from bacteria to humans, involving not only academic, but also applied research	A. M. Araújo, A. C. Turcheto-Zolet, E. K. Santos, F. Bered, F. M. Salzano, L. B. Freitas, K. M. Haag, L. M. Passaglia, M. H. Hutz, M. C. Bortolini, M. H. B. Zanettini, M. P. Margis, N. J. R. Fagundes, S. M. Callegari-Jacques, T. T. Souza-Chies, T. R. O. Freitas, and V. L. S. Valente
	Biotechnology Center, UFRGS	Genomic studies in a wide array of organisms, with academic and applied importance	A. Zaha, A. Schranck, D. Bonatto, G. Pasquali, and R. Margis
	Pontifical University of Rio Grande do Sul	Molecular evolution in many organisms, especially carnivores	E. Eizirik and S. L. Bonatto

[a] Listed in alphabetical order of the first name.

Sérgio Olavo Pinto da Costa graduated in medicine in 1958, and obtained his Ph.D. in 1969, both at the Federal University of Paraná (UFPR), Curitiba. He then moved to São Paulo (Department of Microbiology, Biomedical Sciences Institute, University of São Paulo) where he has remained, but he implemented other research laboratories in Brazil

Table 5 Selected list of molecular medical genetics/genomics research that is presently being carried out in Brazil, with an indication of their main contributors

Place	Institution	Research	Principal investigators[a]
Belém, Pará	Federal University of Pará	Genetic susceptibility/resistance to several tropical diseases and cancer pathogenesis	A. K. C. Ribeiro-dos-Santos, J. M. Guerreiro, and S. E. B. Santos
Salvador, Bahia	Federal University of Bahia	Genetic epidemiology and inborn errors of metabolism	A. X. Acosta
Belo Horizonte, Minas Gerais	Federal University of Minas Gerais	Follow-up of several population cohorts and medical genetics in general	E. Tarazona-Santos and S. D. J. Pena
Rio de Janeiro	Oswaldo Cruz Foundation	Ecological/medical aspects of Amerindian populations and Latin American Study of Congenital Malformations (ECLAMC)	C. E. A. Coimbra Jr., E. E. Castilla, J. C. Llerena Jr., and R. V. Santos
	Federal University of Rio de Janeiro	ECLAMC	I. M. Orioli
Ribeirão Preto, São Paulo	University of São Paulo	Mutagenesis, hematological disorders, and cancer	C. S. Takahashi, E. A. Donadi, J. M. Pìna Neto, and W. A. Silva Jr.
São Paulo	University of São Paulo	Stem cell research, neurogenetics, syndromic diseases, and genetic counseling	A. M. Vianna-Morgante, C. Rosenberg, M. R. Passos-Bueno, M. Zatz, P. A. Otto, and R. C. Mingroni-Netto
		Cardiovascular diseases	J. E. Krieger
Curitiba, Paraná	UFPR	HLA and diseases, especially auto-immune disorders	M. L. Petzl-Erler
Porto Alegre, Rio Grande do Sul	UFRGS	Psychiatric genetics, hemostatic disorders, immunological diseases, teratogenesis, and genetic epidemiology	C. H. D. Bau, E. Bandinelli, F. M. Salzano, J. A. B. Chies, L. Schüler-Faccini, and M. H. Hutz
	Porto Alegre Clinical Hospital	Metabolic diseases, especially inborn errors of metabolism (Reference Center for Latin America), neurogenetics, cytogenetics, and familial cancer	I. V. D. Schwartz, L. Jardim, M. L. S. Pereira, M. Riegel, P. A. Prolla, and R. Giugliani
	Porto Alegre Health Sciences Federal University	Susceptibility/resistance to different types of pathologies	V. S. Mattevi, M. Fiegenbaum, and S. Almeida

[a] Listed in alphabetical order of the first name.

(Jundiaí and Santos (both in São Paulo), Caxias do Sul, Rio Grande do Sul). Three selected items of his list of publications are Rodriguez *et al.* (1990), Luna *et al.* (1997), and Tsuhako and Costa (1998).

In the field of plant genetics, I have again chosen three well-known researchers, though all of them, unfortunately, are now deceased: Alcides Carvalho (1913–1993), Ernesto Paterniani (1928–2009), and Roland Vencovsky (1936–2016).

Alcides Carvalho was the main disciple of C. A. Krug at the IAC and he dedicated his life to the development, study, and improvement of coffee varieties. He graduated in agronomy in 1934, and in the next year joined the IAC staff, where he remained until his death. Most of his publications are in Portuguese, but an account in English can be found in Ferwerda and Wit (1969).

Ernesto Paterniani obtained his Ph.D. under Brieger's mentorship in 1954, but even earlier (1952) he had been part of the Luiz de Queiroz Agronomy School staff. He remained there his entire career and was dedicated to the deep investigation of all aspects of maize history and improvement. Three selected references from his publication list are Paterniani (1969, 1978) and Paterniani and Stort (1974).

Roland Vencovsky obtained a Ph.D. in 1960 and was also a distinguished researcher at the Luiz de Queiroz School of Agriculture in Piracicaba; in addition he was a visiting professor at the North Carolina State University (1990–1991) and Federal University of Goiás (2000–2003). His fields of research were quantitative genetics, population genetics, breeding, and conservation of genetic resources. Selected publications are Tsai *et al.* (1998), Crossa and Vencovsky (1999), and Vencovsky and Crossa (1999).

In the field of human genetics, the researchers chosen here are Newton Freire-Maia, O. Frota-Pessoa, and myself. Newton Freire-Maia (1918–2002) was one of the most important Brazilian geneticists. Born in a small city in the interior of Minas Gerais, he soon developed a strong interest in biology and, after finishing a dentistry course there (the only one available!), he moved to São Paulo at the invitation of Dreyfus. After 5 years of work in the General Biology Department of the University of São Paulo, he accepted another invitation; this time to organize a center of genetic studies at the UFPR in Curitiba. There he remained for the rest of his life, except for stays for studies in several places in the US and Europe. Additionally, in 1970, he worked in Geneva as a scientist in the Human Genetics Unit of the World Health Organization for 1 year. He started his research with *Drosophila*, but soon changed his interest to human genetics. Selected examples of his publications are Freire-Maia (1957), on patterns of inbreeding distribution in Brazil; Freire-Maia (1964) on genetic load; and a main contribution to the etiology of the ectodermal dysplasias, of which he contributed 17 new forms, also classifying and characterizing 160 other different

types (Freire-Maia and Pinheiro 1984). Under Freire-Maia's directorship, the UFPR Genetics Department became one of the most important Brazilian nuclei of excellence in the country.

Oswaldo Frota-Pessoa (1917–2010) also occupies a special place in Brazilian genetics. Born in Rio de Janeiro, he obtained degrees in medicine and natural sciences, as well as his Ph.D., at the Federal University of Rio de Janeiro. He became a member of staff there in 1947, but after a stay in the US at Columbia University and as a staff member of the Pan American Health Organization he moved, invited by Pavan, to work with him in São Paulo. Among his scientific publications, mention can be made of Frota-Pessoa *et al.* (1962), an article on dosage compensation in the Christmas factor of blood coagulation; a review of his work and of others on questions of human population structure (Frota-Pessoa 1971); and the estimation of manifestation risks in Huntington's chorea (Martello *et al.* 1978). Frota-Pessoa was also deeply concerned with science education, publishing a total of 34 textbooks and 17 teaching guides for high school teachers.

At this point, I feel that I should say something about myself. Born in the interior of Rio Grande do Sul in 1928, I obtained a degree in natural sciences at the Federal University of Rio Grande do Sul (UFRGS) in Porto Alegre, and a Ph.D. at the University of São Paulo. My whole career was at UFRGS, and I have lived in Porto Alegre for all these years, except for various stays of different lengths outside Brazil. Among my publications in this period, I would mention Tondo *et al.* (1963), which describes hemoglobin Porto Alegre, a curious silent variant *in vivo* that *in vitro* would polymerize, forming octamers and dodecamers. The variant was employed to investigate natural polymerization processes. Additionally, Neel and Salzano (1967), which describes a type (fission–fusion) of population structure whose properties have been subjected to rigorous mathematical–statistical analyses; and Salzano and Callegari-Jacques (1988), which is a book reviewing all aspects of South Amerindian genetics and evolution in depth.

Molecular genetics and genomics (2000–present)

The start of the field of genomics in Brazil can be dated to 1992, with the studies of Sergio D. J. Pena and Andrew J. Simpson in Belo Horizonte. They obtained expressed-sequence tags from *Schistosoma mansoni*, the worm responsible for schistosomiasis. But the real turning point for Brazilian genomics occurred with the complete sequencing of *Xylella fastidiosa*, a citrus pathogen, in 2000. A series of other studies followed, based on research consortia. A selected list of the organisms whose genomes have been studied in Brazil is given in Table 3. Due to the relative ease of present sequencing with the so-called next-generation sequencing method, the list is certainly incomplete, but it provides a sense of the breadth of organisms tested. Most of them are related to economic (agronomic) or medical interests, but two of them deserve special consideration. The Drosophila 12 Genomes Consortium (2007), with the participation of Brazilian scientists, published data that provided a valuable tool for the investigation of a vast array of *Drosophila* biology. Nonneutral changes were identified in coding and noncoding regions, giving information about the differences in the ecology and behavior of these organisms. The other study, also with a significant Brazilian contribution (Kapheim *et al.* 2015), furnished clues about the process that regulates solitary to group living in 10 species of bees.

An additional example of a study that deals with a fundamental evolutionary question is the one by Melo *et al.* (2016), which is focused on the concept of modularity and its relationship to organismal structure and variation. They investigated the dynamic relationship between modularity and the adaptive landscape (for instance, lines of least resistance to changes, constraints, coselection, and drift).

Table 4 gives a selected list of 73 geneticists, working in 18 Brazilian cities. As for the preceding table, this one makes no attempt to be comprehensive and only gives a general view of the places, people, and subjects presently being investigated in Brazil. The places where the research is being carried out extend all over the country, from the Amazonian north (Belém) to the southern cone (Porto Alegre), and includes a vast array of subjects and organisms.

A list similar to that of Table 4 is given in Table 5, regarding molecular medical genetics/genomics in Brazil. The list is even more incomplete than that of Table 3, but gives information about research being carried out in eight cities, by 38 investigators. Medical genetics/genomics is thriving in Brazil; these workers have their own national society and are engaged in a large number of research projects. Two international networks should be mentioned: the Latin American Study of Congenital Malformations (ECLAMC in the Spanish denomination), coordinated in Rio de Janeiro and Buenos Aires by Eduardo E. Castilla and Iêda Orioli; and the Latin American Reference Center for Inborn Errors of Metabolism, headed by Roberto Giugliani in Porto Alegre. Both have been operating for several decades now, and their results have furnished important data for these two areas of study.

In terms of international collaboration and interchange, a specific event should be mentioned: the Porto Alegre Biological Evolution Workshops. Five of these workshops were held between 2007 and 2015. They were organized in a format that allowed ample time for discussion and they assembled some of the most important world authorities in the subject, who debated the most exciting problems in evolutionary biology with Brazilian and Latin-American scholars. In addition, they served as initial contacts for the establishment of joint research programs. They could be a good example of what we hope will occur in the XXII International Congress of Genetics, to be held in Brazil (Foz do Iguaçú, September 10–14, 2018) in the near future. This will be the first international congress of genetics to be held in South America.

Overview and Perspectives

It might be asked whether genetics/genomics in Brazil developed better or worse than other Latin-American countries. However, different areas and population sizes, as well distinct histories and socioeconomic development (*cf*. Salzano and Bortolini 2002) complicate any such comparisons. In general, the evaluations using different indices of scientific achievement favor Brazil, but the situation may be different in distinct areas, and there is no published analysis comparing genetics/genomics specifically.

I have covered almost a century (from 1933 to 2017, 84 years) of the development of genetics/genomics in Brazil and it can be seen that, despite all the problems of underdevelopment and the periodical political and economic crises, these two related fields have developed reasonably well in our country. Furthermore, many of our researches are in good company at the forefront of science, as carried out by our colleagues in the more fully developed nations. At present, following international trends, the Brazilian political and economic situations are far from stable. We have already faced such times in the past, however, and I am optimistic for the future. Despite all world cycles of misunderstandings and obstacles to the development of science, no other social institution can be compared to science in the promotion of human well-being and happiness. Science requires optimism and I am fairly optimistic about the future of genetics and genomics in Brazil.

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