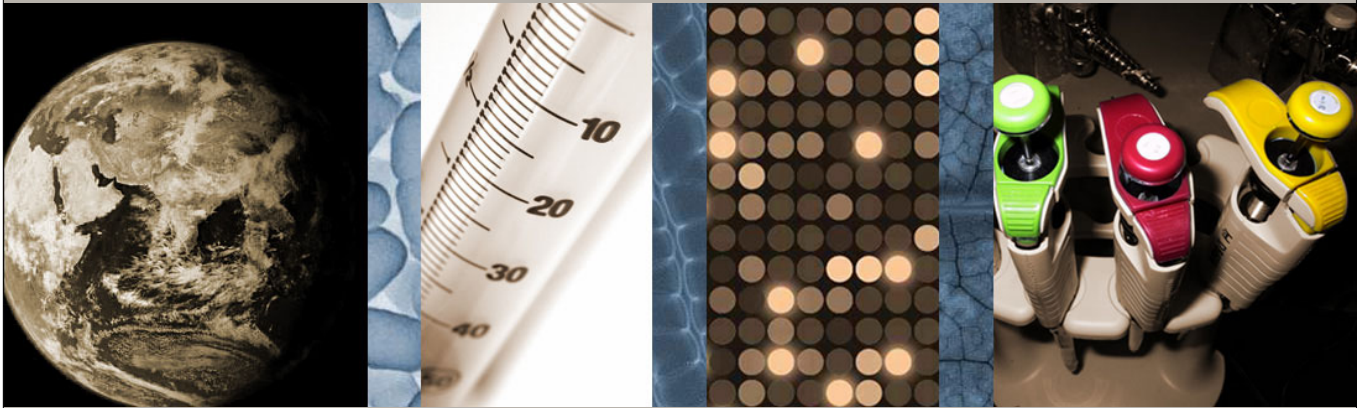


Science-Matrix

Scientometric Study

June 2004



Benchmarking of Genomics and Health Biotechnology in Seven Developing Countries, 1991-2002

Brazil, China, Cuba, Egypt, India,
Republic of Korea and South Africa

Prepared for
University of Toronto
Joint Center for Bioethics

Science-Metrix

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Frédéric Bertrand and
Grégoire Côté

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Executive summary

This scientometric study provides an extensive quantitative analysis of the performance of leading countries, as well as seven selected developing countries, in the domains of genomics and health biotechnology using the Science Citation Index (SCI) Expanded scientific papers database. Papers were retrieved from SCI Expanded using two sets of keywords, one for genomics and one for health biotechnology. All genomics and health biotechnology papers were normalized at the country and city levels. Therefore, significant effort was put into normalizing data for developing countries, in order to categorize institutional sectors of activity with a minimum level (1% to 4%) of unknowns, and to precisely identify the most active institutions and researchers.

Using a ten year time frame (1991-2001), the report outlines the evolution of genomics and health biotechnology at the international and national levels in leading developed countries, as well as in seven developing countries. The report presents the scientific output performances of the developing countries using five scientometric indicators and a combined multicriteria ranking.

Increasingly, developing countries are rapidly gaining a presence in the world's scientific community for life sciences. China and the Republic of Korea in particular will, in the near future, enter the league of leading countries and will overtake so-called developed countries in terms of absolute scientific output in genomics and health biotechnology. As the international community stresses the need to apply genomics and health biotechnology R&D to improve global health and sustainability in developing countries, the next decade might provide these countries with the necessary knowledge and know-how to solve the most prevalent issues of poverty, disease, high population density, and environmental problems. However, it would be of great interest to monitor and study the integration and application of the blossoming domains of biotechnological and genome science to local health and well-being needs, in order to provide insight to the developing nations that have limited scientific and technological resources.

Key findings

Genomics at the international level

- Between 1991 and 2002, papers in genomics increased by almost 60% at the world level; specifically, from approximately 35,000 to over 55,000 scientific papers annually.
- In terms of the percentage of genomics papers in the SCI Expanded database (world), growth was somewhat slower (approximately 30%); specifically, from 6% in 1991 to 7.7% in 1998, after which it oscillated between that level and 7.4% of the total number of papers referenced in SCI Expanded.

Leading countries

- During the 12 years studied, Canada consistently ranked 6th among the 12 leading countries. In fact, the ranking of the seven leading countries was highly stable, where the G7 nations are also the G7 genomic countries. Italy ranks 7th, behind Canada, but is likely to be more productive than Canada over the next few years. Canadian genomics is stable in terms of output, but its impact is increasingly gaining importance.
- In terms of number of papers per capita, Switzerland and Sweden are in a league of their own, occupying the 1st and 2nd rank respectively.
- Japan has become the clear leader in terms of specialization in genomics.
- The United States and Switzerland both have papers in genomics whose expected impact is considerably higher than that of other countries (by 19% and 16% respectively). Although the United States had the highest number of expected citations (i.e.: impact factor), it is Switzerland that had the greatest number of observed citations per paper on average. Canada published in journals that were cited 6% more than the world average.
- During the 12-year period observed here, the United States and Switzerland were the clear winners in the multicriteria ranking. Canada made some progress during the period studied: it was in 10th place during the 1991-1993 period, moved to the 7th rank in 1994-1996, then to 6th during the 1997-1999 period, and finally dropped back into 8th position in 2000-2002, for an overall average rank of 7.

Developing countries

- Between 1999 and 2002, the most emergent developing country in genomics was China, in 3rd position with a 22.1% growth rate. China's score can be considered as exceptional if we take into account that China occupied a merely respectable 15th position in terms of the absolute number of publications.
- The Republic of Korea follows China in terms of absolute output (19th place with 6,207 papers) and growth rate (11th place with 13.1%).
- China and the Republic of Korea are set to enter the league of leading countries in the next few years.
- Most developing countries publish below the world average of nine papers per million inhabitants; the exception is the Republic of Korea, whose overall average is 11 papers per million inhabitants.
- In terms of specialization index, Cuba and the Republic of Korea came close to the world average, with the remaining developing countries being greatly under specialized in genomics.
- Amazingly, the Republic of Korea has improved its specialization index in genomics from 0.49 in 1991-1993 to 0.98 in 2000-2002. Along with Cuba, the Republic of Korea is about to become the most specialized developing nation studied, with a specialization index close to that of Spain and the world average.
- South Africa published in the journals most often cited. However, South African genome science did not reach the average world level of scientific impact.
- South Africa and Cuba's average relative citations grew steadily over the studied 12-year period. This is reflected by their ranking. South Africa occupied the 1st place among the seven developing countries and Cuba was 2nd.
- Based on a multicriteria ranking of 60 countries in genomics, the Republic of Korea is one of the fastest growing developing countries; it gained 12 positions during the four periods studied.
- According to this multicriteria ranking of 60 countries, the seven developing countries ranked as follows: Republic of Korea was 1st, ranking 28th overall. South Africa was 2nd, in 36th place. South Africa was followed closely by 3rd place Brazil who ranked 38th overall. 4th was Cuba, further behind in 43rd place, followed China (5th) in 51st place, India (6th) in 54th position and, finally, near the bottom of the ranking, Egypt (7th) in 57th position.
- As a group, the seven developing countries principally collaborated with the leading countries in genomics: United States (50.2%), Japan (12.7%), United Kingdom (12.2%), Germany (8.3%), France (7.0%), and Canada (4.4%). This distribution is about the same as the share of these developed countries in the domain. Taken individually, seven developing countries show preferential collaboration patterns towards certain countries. Taken as a group, however, developing countries collaborate proportionally with the leading countries' scientific output in genomics.
- Overall, like Canada, the developing countries studied published more genomic papers, proportionally, with international collaborators (more than 40% of the genomics papers) than with national collaborators.
- In the Republic of Korea there was more collaboration between national counterparts than there was between Korean institutions and international partners. As in the Republic of Korea, Brazil and China are increasingly moving toward national collaboration in genomics and further away from international collaboration.
- Egypt has a fairly high international collaboration rate (74.6% in 2002), but also the lowest national collaboration rate (11.1% in 2002), which points to Egypt's scientific dependence on international activity in genome science.
- In terms of the proportion of all papers published in collaboration with international partners, the developing countries that collaborated most with Canada were Brazil (5.7%) and Cuba (5.5%); in terms of the absolute number of papers published in collaboration, Brazil (131 papers) and China (112 papers) collaborated most with Canada.

Health Biotechnology at the international level

- At the world level, the number of papers went from about 10,000 in 1991 to about 12,000 in 2002, an increase of approximately 1% over the 12-year period.
- The proportion of health biotechnology papers in the SCI Expanded database decreased over the period studied; dropping from 1.8% in 1991 to 1.6% in 2002, with its peak in 1994 at 1.9%. After examining these numbers, it is safe to assume that this research sector is stable and has reached a plateau in its expansion at the world level.

Leading countries

- During the 12 years studied, the United States had an amazing performance in health biotechnology: it occupied the 1st position with 59,865 publications; a number that was significantly higher than the 18,332 publications produced by Japan, who ranked second.
- Canada consistently ranked 6th among the 12 leading countries. In fact, the ranking of the seven leading countries was highly stable. As was the case in genome science, the G7 nations are also the G7 health biotechnology countries.
- As was the case in genomics, Switzerland and Sweden are head and shoulders above other nations with respect to the number of papers per capita, occupying the 1st and 2nd rank respectively.
- In terms of specialization in health biotechnology, Switzerland is the leader among the leading countries. Canada was last, save Spain, in terms of the specialization index.
- The United States and Switzerland both have papers in health biotechnology whose expected impact is considerably higher than that of other countries (by 20% and 13% respectively). They are followed by Canada and the Netherlands, which both published health biotechnology papers in journals that were cited respectively 7% and 6% more than the world average for health biotechnology.
- Contrary to the situation in genomics, the United States managed to keep its 1st place in terms of average relative citations. Nonetheless, we can safely assume that Switzerland will surpass the United States in the short term for this indicator.
- Using the multicriteria ranking, Switzerland was the uncontested champion. The Netherlands were 2nd, the United States 3rd, and Belgium 4th. The United Kingdom was 5th, Denmark 6th, Sweden 7th, Austria and Canada 8th, and France 10th.

Developing countries

- The Republic of Korea gained remarkable ground in terms of number of papers, beginning in 25th position in 1991-1993 and finishing 12th in 2000-2002, ahead of Switzerland, with an overall rank of 14th over all four periods.
- China's growth is as impressive: starting in 22nd place in 1991-1993, it finished an amazing 14th in 2000-2002, with an overall average of 19th.
- India, Brazil, Egypt, and Cuba all improved their positions steadily during the 12 years studied.
- Most developing countries publish below the world average of two papers per million inhabitants.
- Again, it is important to emphasize the remarkable performance of the Republic of Korea, with an overall average of four papers per million inhabitants, making it the only developing country studied to have surpassed the world average benchmark.
- All the developing countries studied improved their specialization index during the 12-year period. Nonetheless, only Cuba and the Republic of Korea were above the world average, the rest of the developing countries being greatly under specialized in health biotechnology.
- Cuba was the most specialized country in the world during the period studied, with an average specialization index of 2.63.
- In the case of developing countries, none had an average relative impact factor (ARIF) above the world average of 1. South Africa was the closest to the world benchmark, with an average of 0.81 for the 12-year period as a whole. Brazil (0.74), Korea (0.72), and Egypt (0.72) come in next, with Cuba (0.57), India (0.57), and China (0.54) not far behind.
- Despite its far-fetched growth in scientific output, the Republic of Korea experienced a strong drop in ARIF, passing from 18th to 40th position.
- As in the case of the ARIF, none of developing countries had average relative citations above the world average. Here, too, South Africa, Brazil, and Korea occupied the first three places among the developing countries.
- Based on a multicriteria ranking of 45 countries in health biotechnology, the Republic of Korea ranked 1st with its 21st place with Brazil's 2nd place ranking 30th overall. Brazil is immediately followed by South Africa (3rd) in 31st place and Cuba (4th) in 32nd place, with India (5th) in 38th place, and China (6th) in 40th place. Egypt (7th) occupies the 45th and final position.

- As in genomics, the distribution of international collaborations is roughly the same as the share of most active developed countries in the domain. Again, taken individually, the seven developing countries show preferential collaboration patterns towards certain countries and, taken as a group, proportionally with the leading countries' scientific output in genomics.
- Developing countries generally published more papers in health biotechnology with international collaborators than with national collaborators (more than 30% of the health biotechnology papers published).
- As was the case in genomics, two developing countries do not follow the trend toward international collaboration: the Republic of Korea and India. The same collaboration dynamic can be observed in Brazil, China and Cuba with a trend toward more national collaboration.

Developing countries' scientific output at the national level

Genomics by field and subfield

- The most prolific fields in genomics are Biomedical Research and Clinical Medicine.
- All developing countries have the same level of world effort in Biomedical Research except for China and Egypt that are less specialized. Conversely, China and Egypt were the only countries with a specialization index that was near or just above the world average (0.94 and 1.07) in Clinical Medicine. Overall, we can assume that the clinical portion of genomic research in developing countries is underrepresented in comparison to what is observed at the world level.
- Biomedical Engineering is quite important in Biomedical Research in three countries highly specialized in this subfield (India, the Republic of Korea, and Cuba).
- In genomics, Biology is the only field in which all developing countries are more specialized than the world average. In contrast, many of the leading developed countries are not specialized in the field of Biology. This includes the United States (0.79), the United Kingdom (0.88), the Netherlands (0.93), Sweden (0.74), Switzerland (0.68), France (0.84), Germany (0.92), and Italy (0.73).
- China dominates Chemistry, followed by India and the Republic of Korea.

Health biotechnology by field and subfield

- Within health biotechnology, all seven developing countries studied keep pace with the world's degree of specialization in Biomedical Research, but this is not the case in Clinical Medicine. The most specialized countries in Biomedical Research are India and the Republic of Korea, each with over 30% more papers in this field, proportionately, than the world average. Both countries had a high degree of specialization in Biomedical Engineering (over 300% more specialized than the world in this subfield of health biotechnology).
- As was the case in genomics, Cuba is also specialized in health-biotechnology-related Biomedical Engineering (46 papers, S.I. of 3.75).
- We can therefore assume that health biotechnology R&D is not clinically oriented in the developing countries studied compared to the developed countries.

National scientific output by sector of activity

- In developing countries, the patterns of sector-based scientific contribution are similar for both genomics and health biotechnology. However, in some countries, governmental institutions are proportionally more active in health biotechnology than they are in genomics.
- With the exception of Cuba scientists from universities in developing countries authored the majority of the papers in genomics and health biotechnology, so that universities dominate both domains.
- In both domains, governmental institutions are proportionately more active than clinics and hospitals are in the developing countries studied; however, this is not the case for China, where universities hold the lion's share. Cuba stands out for the number of papers published by governmental institutions, with 88% of genomics papers and 97.2% of health biotechnology papers produced by governmental institutions.
- As with Cuba, albeit to a lesser extent, government also plays an important role in Indian and Chinese R&D in both domains. In fact, in India and in China, governmental institutions are responsible for more than 35% of their respective scientific output in genomics and health biotechnology.
- South Korean companies are exceptionally prolific, and well positioned in genomics and health biotechnology, in comparison with the other developing countries studied.

Most active cities and institutions

Brazil

- In terms of the number of publications, Sao Paulo was the most active city in Brazil with 1,637 papers in genomics and 428 in health biotechnology.
- The leading institutions include the Universidade de São Paulo in 1st place for both genomics and health biotechnology, the Universidade Federal do Rio de Janeiro in 2nd place in genomics and 3rd place in health biotechnology, and the Fundação Oswaldo Cruz governmental institute in 3rd place in genomics and 2nd place in health biotechnology.

China

- In China, Beijing is the most active city in both domains, having published 2,472 papers in genomics and 623 in health biotechnology.
- In China, the main institutions contributing to publications in genomics and health biotechnology come from the governmental and the university sectors. The Chinese Academy of Sciences dominates in terms of scientific output. This governmental institution ranks 1st in genomics with 1,703 papers and also in health biotechnology with 318. Fudan University leads the university sector with 590 papers in genomics and 170 papers in health biotechnology. Overall, seven universities published more papers than the country average for most active institutions in genomics, and eight universities did so in health biotechnology.

Cuba

- In Cuba, most of the scientific activity in genomics and health biotechnology is concentrated in Havana, which holds 90% of the papers in genomics and 95% of the papers in health biotechnology.
- Most scientific activity in Cuba is concentrated in the government. The Centro de Ingenieria Genética y Biotecnología on its own accounts for half of Cuba's production in both domains, with 174 papers in genomics and 119 papers in health biotechnology.

Egypt

- With 253 papers in genomics and 91 papers in health biotechnology, Cairo is the most active city in Egypt.
- In Egypt, the main institutions contributing to publications in genomics and health biotechnology come from the university and governmental sectors. The Cairo University occupied the 1st rank in genomics with 123 papers and in health biotechnology with 33 publications. The National Research Center is the leading institution within the government and ranked 4th in genomics and 3rd in health biotechnology.

India

- In India, New Delhi, with 1,294 papers in genomics and 429 papers in health biotechnology, is the most active city.
- With 524 papers in genomics and 117 papers in health biotechnology, the most active institution, the Indian Institute of Science, is from the university sector. However, when grouping institutes from the same governmental entity, the Council of Scientific & Industrial Research (CSIR) ranks 1st, followed by the Indian Institute of Science and the Indian Council of Agricultural Research (ICAR).

Republic of Korea

- In the Republic of Korea, Seoul is the clear leader in both genomics and health biotechnology, holding about 50% of the country's papers in both domains.
- Seoul National University is clearly the country's leader with 1,587 papers in genomics and 471 papers in health biotechnology. Among developing countries, South Korean companies are the most active in peer-reviewed publishing.

South Africa

- Johannesburg and Cape Town are clearly the two most active South African cities in both genomics and health biotechnology in terms of the absolute number of papers.
- Leading institutions are principally from the academic sector. The four most prolific universities in both domains are the University of Cape Town, the University of the Witwatersrand, Stellenbosch University, and the University of Pretoria.

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1 Introduction

The Joint Centres for Bioethics (JCB) of the University of Toronto mandated Science-Metrix to measure scientific activity of developing countries in genomics and health biotechnology. This project aims to provide quantitative material for JCB's project under the Canadian Program in Genomics & Global Health, entitled "Genome Innovation Systems in Developing Countries". The present interdisciplinary collaborative project, with the participation of local experts, aims to analyze the innovation systems in genomics and in health biotechnology in the following seven developing countries: Brazil, China (Mainland China)¹, Cuba, Egypt, India, the Republic of Korea, and South Africa.

Health is a major topic in developing countries. Millions of people die each year from diseases that could be prevented or treated inexpensively and simply in the future through the development and use of a limited number of promising biotechnologies². Modern biotechnology, combined with the recent advanced in genomics, could greatly improve global health through their application and integration in different sectors of developing economies such as medical/pharmaceutical, agricultural, and environmental sectors.

During the last decade, genomics (and other related biotechnologies) has increasingly received political and financial support from Governmental institutions in many developing countries. The research and development activities that focuses on these enabling technologies in developing countries is still likely to be limited in resources, compared to more industrialized countries, but is expanding and impressive. Emerging and growing biotechnology industries, together with a highly educated community of researchers and strong government support is observed in developing countries^{3,4,5}. Many Biotech parks have been established in numerous developing countries in order to maximize the integration of academic, governmental, and private research⁶.

Although the domains of genomics and health biotechnology are highly important, not only because of the current levels of investment in research worldwide, but also because of all the promises it holds for improving global health and sustainability, there are few current studies that compare the level of scientific achievement of the most active developed countries. To fill this gap, Science-Metrix

¹ In this study, the definition of China is based on mainland China geographical limits.

² Abdallah S. et al. 2002. Top ten biotechnologies for improving health in developing countries. *Nature Genetics*, 32:229-232.

³ Padmanaban, G. 2003. Growth of biotechnology in India. *Current Science*, 85(6): 712-718.

⁴ *India's Biotech Industry: Segment Review*. India Economic News, Published for the Embassy of India (Economic Wing), Washington, DC.

⁵ Choi K.Y., Hahm K.-S., Rhee S.-K. and Han M.I. 1999. An overview of biotechnology in Korea. *Trends in Biotechnology*, 17(3): 95-101.

⁶ DaSilva E. J., Baydoun E. and Badran A. 2002. Biotechnology and the developing world. *Electronic Journal of Biotechnology (JEB)*, 5(1): 64-92.

presented, in 2003, to Genome Canada a scientometric-based benchmarking study of the leading countries in genomics⁷. However, studies that have extensively characterized and benchmarked the scientific output of developing countries in genomics and in health biotechnology are nonexistent to this date. Again, this scientometric study aims to fill this gap.

In this report, we use two sets of keywords to delineate genomics and health biotechnology. These sets have been defined over the years by the authors of this report in collaboration with external experts. These keywords are used to build two basic corpuses of papers in genomics and in health biotechnology extracted from Thomson-ISI's *Science Citation Index Expanded* database. The methods are described in greater detail in the following section.

This scientometric study is divided into three main sections. The first examines how leading and developing countries compare in terms of scientific output in genomics at the international level (Section 3), while the second examines their performance in health biotechnology (Section 4). These two sections are symmetric in scientometric data presentation and analyses. After a global overview of trends in terms of scientific output and growth of the top 60 countries in genomics and the top 45 countries in health biotechnology, each section ranks the top 12 leading countries and the seven developing countries using a series of scientometric indicators, including number of papers, specialization index, impact factor, and number of citations. These indicators are subsequently combined in a multicriteria analysis that aims to provide a synthetic picture of genome science and health biotechnology at the international level. International and national collaboration rates are also analysed.

Whereas the two previous sections examined how developing countries compared to the rest of the world in genomics and health biotechnology, the third section examines, in detail, the distribution of scientific output of the seven countries at the national level (Section 5). After looking at data desegregated by field and subfield for each of the domains and at the distribution of papers by sectors of activity, it subsequently benchmarks the most active cities and institutions for each developing country.

⁷ Archambault É., Côté G. and Bertrand F. 2003. *Benchmarking of Canadian Genomics - 1991-2002*. Prepared for Génome Canada by Science-Metrix, 49 pages.

2 Methods

Scientometric analysis

This scientometric study is based on the use of the Thomson ISI Science Citation Index Expanded database (SCI Expanded), which contains papers from more than 6,000 journals⁸. These journals are considered to be the most important peer-reviewed journals in their respective fields. They reflect significant scientific achievements and are the most widely cited journals in the world (over 80% of the world's citations). The statistics are drawn from four document types that are considered to be original contributions to scientific knowledge: articles, notes, reviews, and conference proceedings. The tables presented in this report refer to these four document types as "papers". This scientometric analysis is based on two subsets of papers from the SCI Expanded database, characterizing two scientific domains: genomics and health biotechnology. Both datasets are not exclusive as one paper may pertain to both domains.

Domains definition

Genomics - The study of genomes, specific genes and their function.

The definition includes classical genomics which focuses on gene and DNA sequencing as well as functional genomics, and bioinformatics. It also includes research that uses these genome-based technologies to most efficiently pursue questions in the life sciences (e.g. agriculture, food science, environmental sciences, medicine, pharmaceutical sciences, general biology and ecology).

Operationally, the construction of the genomics dataset is essentially based on the use of keyword-in-title searches. This query method has been fine-tuned over the years and was originally defined by experts appointed by Genome Canada and by analysts now working at Science-Metrix. The keywords have been tried and tested. The search expression used selects papers in core and in peripheral genomics (such as papers in molecular biology that touch upon the genome).

Health biotechnology - The application of scientific and engineering principles to the processing of organic and inorganic materials by biological agents (biological organisms or biological substances) to provide goods and services in the health sector.

This definition covers biotechnology in the fields of clinical medicine and biomedical research. Operationally, the construction of the health biotechnology dataset is also based on the use of keyword-in-title searches. The keywords were selected as follows: first, papers were randomly selected from journals specialized in biotechnology; keywords and keyword combinations were then chosen from the titles of these papers in order to retrieve other papers in the field of biotechnology. Afterwards, the biotechnology keyword set was validated using the SCI Expanded database with a goal of selecting papers specific to the domain of health biotechnology.

⁸ Data derived from information prepared by the Institute for Scientific Information, Inc. (ISI, Philadelphia, Pennsylvania, USA). Copyright Institute for Scientific Information. All rights reserved.

Addresses from papers were standardized according to country and city, and were coded at the sector levels (University, Government, Clinics & Hospitals, Company, and Other). In this study, the definition of China is based on mainland China geographical limits.

Indicators

The resulting datasets were used to produce detailed statistics based on the following indicators:

Number of papers - Number of scientific papers written by authors located in a given geographical, sectoral, organizational, or individual entity (e.g.: countries, cities or institutions).

Specialization index - This is an indicator of the intensity of research of a given geographic or organizational entity (e.g.: country) in a given research area (domain, field) relative to the intensity of the reference entity (e.g.: world) in the same research area. The specialization index can be formulated as follows:

$$SI = \frac{(X_s / X_T)}{(N_s / N_T)}$$

where

X_s = Papers from entity X in a given research area (e.g.: Canada in the domain of genomics)

X_T = Papers from entity X in a reference set of papers (e.g.: Canada in the whole SCI Expanded database)

N_s = Papers from the reference entity N in a given research area (e.g.: world in the domain of genomics)

N_T = Papers from the reference entity N in a reference set of papers (e.g.: world in the whole SCI Expanded database).

An index above 1 means that a given entity is specialized, relative to the reference entity. Conversely, a score below 1 means that the given entity is not specialized, relative to the reference entity.

For the current study, the specialization index as computed for domains (genomics and health biotechnology) uses the whole SCI Expanded database as a reference set of papers. The specialization index as computed for fields and subfields uses the domain as a reference set of papers.

Average relative impact factor - This indicator is a proxy for the quality of the journals in which an entity publishes its papers. Each journal has an annual impact factor (IF), based on the number of citations it received, relative to its number of papers. Then the journal's IF is ascribed to its papers. Each paper's IF is divided by the average IF of all papers in its subfield to obtain a Relative Impact Factor (RIF). The average relative impact factor (ARIF) of a given entity is computed using the average RIF of each paper belonging to it. When the ARIF is above 1, this

means that an entity scores better than the world average for a given field; when it is below 1, this means that on average, an entity publishes in journals that are not cited as often as the world average.

Average relative citations - This indicator is a proxy for the quality of papers produced by a given entity. The number of citations received for each paper was counted for the year in which they were made and for the two subsequent years. For papers published in 1991, for example, citations received in 1991, 1992, and 1993 were counted. The only exceptions are 2001, which comprises a citation window of two years (2001 and 2002), and 2002, which contains a citation window of one year, since citation data was not yet available for the subsequent years. For a paper in a given specialty, the citation count was then divided by the average count of all papers in this specialty to obtain a relative citation count (RC). The average relative citations (ARC) of a given entity are computed using the average RC of each paper belonging to it. When the ARC is above 1, this means that an entity scores better than the world average in a given field; when it is below 1, this means that, on average, an entity publishes papers that are not cited as often as the world average.

National collaboration rate - This is an indicator of the relative importance of inter-institutional collaboration within a country for a given entity. The rate is computed by dividing an entity's number of papers that have two or more institutions in their address fields by the entity's total number of papers.

International collaboration rate - This is an indicator of the relative importance of international collaboration. The rate is computed by dividing an entity's number of papers that have at least one foreign country in their address fields by the entity's total number of papers.

3 Genomics at the International Level

This section presents data on the global rate of growth of scientific papers written in the domain of genomics at the world level (Section 3.1). It subsequently benchmarks the scientific output of the seven developing countries against that of other leading countries including Canada (Section 3.2).

3.1 Global trends in genome science

The number of papers in genomics at the world level grew steadily until 1998, when it reached “cruising speed” (Figure 1), increasing from approximately 35,000 scientific papers in 1991 to more than 55,000 in 2002; an increase of nearly 60% over the 12-year period. In terms of the percentage of genomics papers in the SCI Expanded database, growth was somewhat slower, rising from 6% in 1991 to 7.7% in 1998 (almost 30% growth), after which it oscillated between that level and 7.4% of the total number of papers in SCI Expanded.

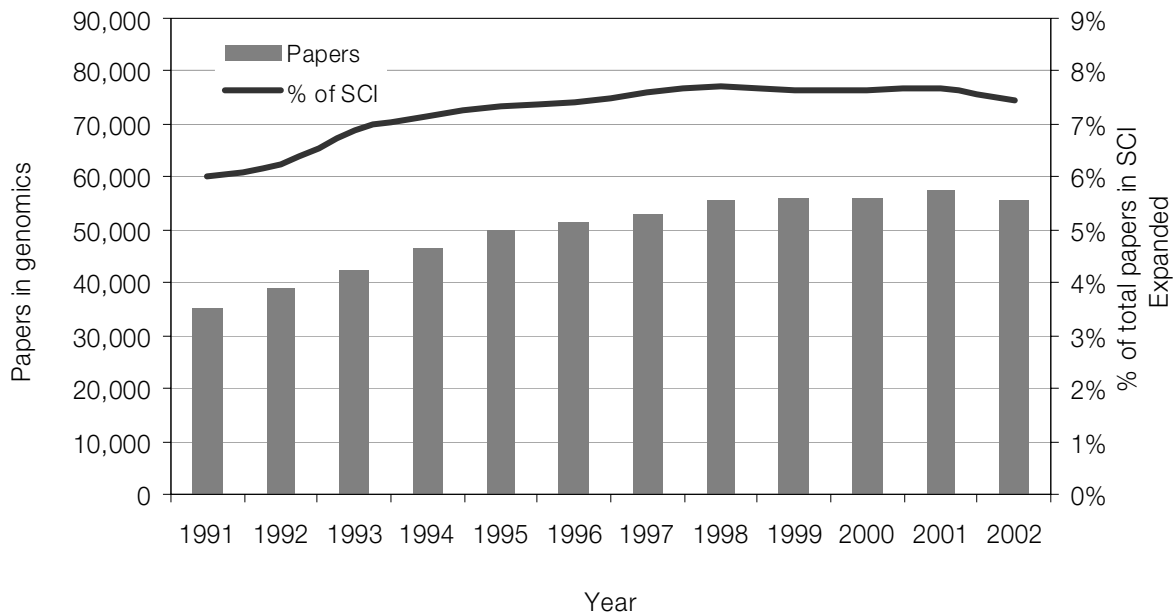


Figure 1 Papers in genomics in SCI Expanded, 1991-2002

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Figure 2 shows the number of papers in genomics by the 60 leading countries. Canada's output of papers in genomics during the 12 years studied is consistent with the place it occupies among the G7 countries. In fact, the G7 economic countries are also the G7 genomic countries. Data presented in Section 3.2 show that, during the 12 years studied, Canada consistently ranked 6th among the 12 leading countries when considering four three-year periods. In fact, the ranking of the seven leading countries was highly stable, with all countries keeping the same rank.

As one can see in Figure 2, there is a discontinuity in the number of papers published in genomics by the 12 most active countries, the number of papers by countries following Switzerland being

substantially lower than that by the 12 leaders. Nonetheless, China's performance in publications (15th) is still close to that of Switzerland (three positions behind Switzerland, with China having published 7,063 papers and Switzerland 13,522). China's total scientific output in genomics between 1991 and 2002 was about the same as that of Denmark (7,304 papers) and Finland (6,785 papers), and was close to that of the Russian Federation (8,504) and Belgium (8,835).

Not far behind China, the 19th and 20th positions are held respectively by the Republic of Korea (6,207 publications) and India (6,145 publications). Brazil follows in the 23rd position with 4,547 papers. The Brazilian output in genomics is barely comparable to that of Taiwan. The next country of interest for the purposes of this study falls far behind: South Africa occupies the 32nd place with 1,902 publications, an output comparable to that of Argentina and Hong Kong. Egypt is even farther behind, in 42nd place with 573 publications. Finally, Cuba is in 52nd position with only 321 publications.

Figure 3 shows the average yearly growth of papers in genomics as observed from 1999 to 2002 (average of three growths periods: 1999 to 2000; 2000 to 2001; 2001 to 2002). An analysis of the last four years of the 12-year period studied suggests the most recent annual growth trends.

While the seven developing countries central to this study did not occupy leading positions in terms of their absolute number of papers published, most showed a high rate of growth in terms of genomics publications. In fact, six of the seven developing countries experienced stronger annual growth (more than 5%) than the 12 most prolific countries in terms of the absolute number of papers published.

Indeed, over the last four-year period, the most emergent developing country in genomics was China, in 3rd position with a growth rate of 22.1%. China's score is exceptional if we take into account that China occupied the 15th position in terms of the absolute number of publications. China's growth score is comparable to that experienced by Portugal, Iceland, and Thailand. It is interesting to note that Hong Kong has a slightly lower growth than its continental counterpart, ranking 8th and having witnessed a growth rate of 18.4%. The developing country to follow China in terms of growth is the Republic of Korea, in 11th place with a growth rate of 13.1% (19th position in terms of absolute number of papers published). Furthermore, from the list of countries with a high annual growth rate (more than 5%) between 1999 and 2002, China and the Republic of Korea were the two most prolific countries in terms of their number of papers. From this, we can assume that Asian nations are becoming increasingly important in the international genomics community. Currently, China and the Republic of Korea appear to be the two most promising producers of genomic knowledge in the world over the next few years.

After China and the Republic of Korea, Brazil and India were the two most prolific developing countries in terms of number of papers and average annual growth rate. Indeed, between 1999 and 2002, Brazil and India respectively occupied the 21st (7.8% average annual growth) and 24th (9.6% average annual growth) positions in terms of growth and 18th and 21st positions (1991-2002) in terms of absolute number of papers published.

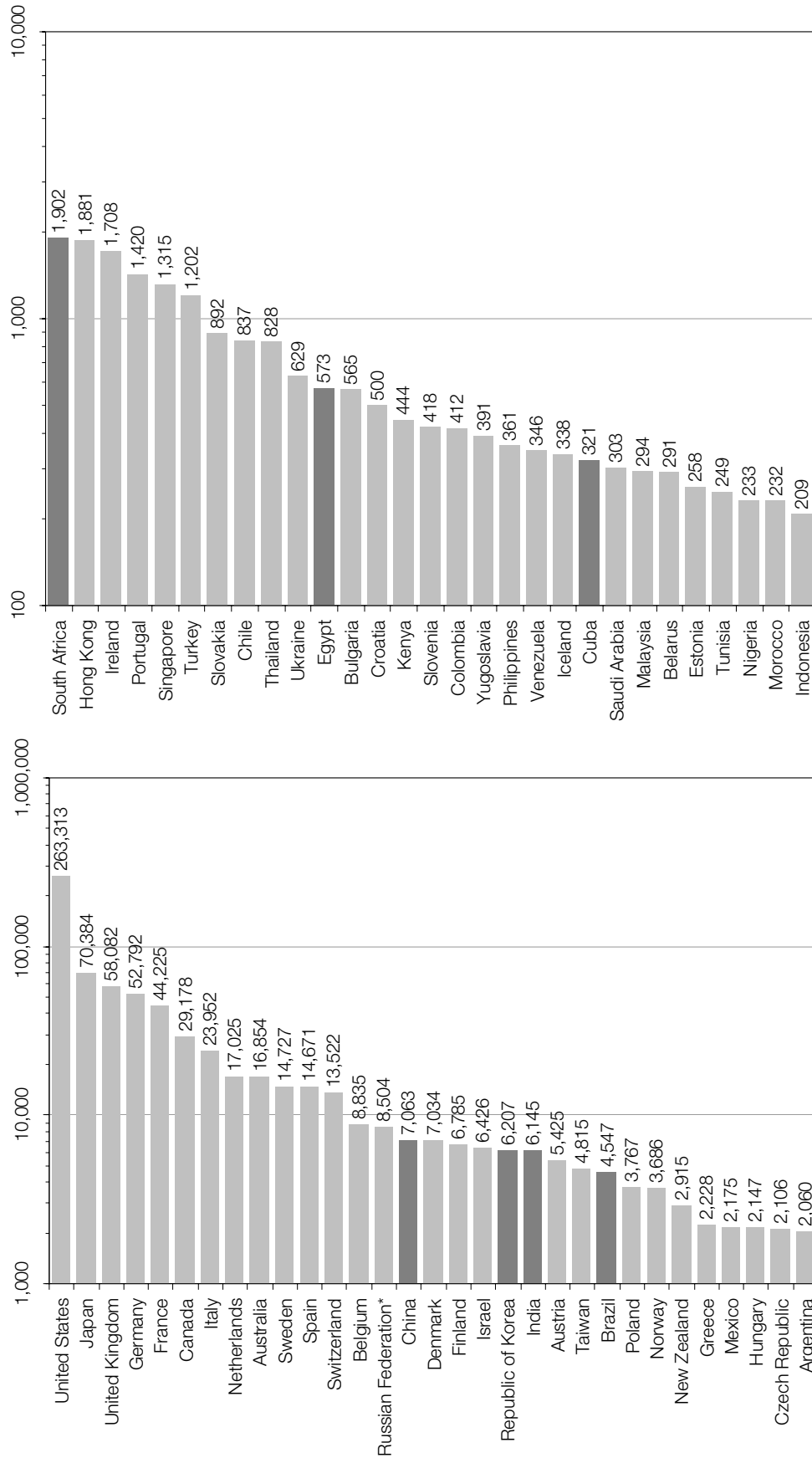
South Africa reached 32nd place, with its average growth (5.1%) being higher than that of the 12 leading countries, most of which find themselves near the bottom of the ranking in terms of growth.

Cuba's 33rd position (average annual growth of 5%) can be partially explained by the fact that its total number of publications is still very small, making it easier for the country to register strong growth. This is also true for many of the countries that experienced greater than 5% average annual growth (i.e.: Saudi Arabia, which was in 1st position and experienced 27.3% growth between 1999 and 2002 with an average of 30 papers per year). In fact, genome science is probably a more mature domain in leading scientific nations, but developing countries seem to be picking up speed in this domain. Additionally, the increased contribution by developing countries to Anglo-Saxon scientific and technical journals listed in international citation databases also explains their growing presence in genomics.

Finally, Egypt is in the 57th position in terms of growth. Like Cuba, the small number of papers published annually by Egypt disproportionately affects its growth (-2.4%). In fact, between 1999 and 2002, Egypt's scientific output was roughly the same every year, with 60, 68, and 63 papers respectively.

The next section benchmarks in more detail the leading and developing countries using five evaluation criteria. A multicriteria analysis of the five indicators is also presented, followed by information on the dynamics of scientific collaboration in developing countries.

Genomics and Health Biotechnology in Seven Developing Countries



* Papers for 1993-2002 in the case of the Russian Federation

Figure 2 Top 60 countries by number of papers in genomics (log scale), 1991-2002
 Source: Compiled by Science-Matrix from data prepared by ISI Thomson.

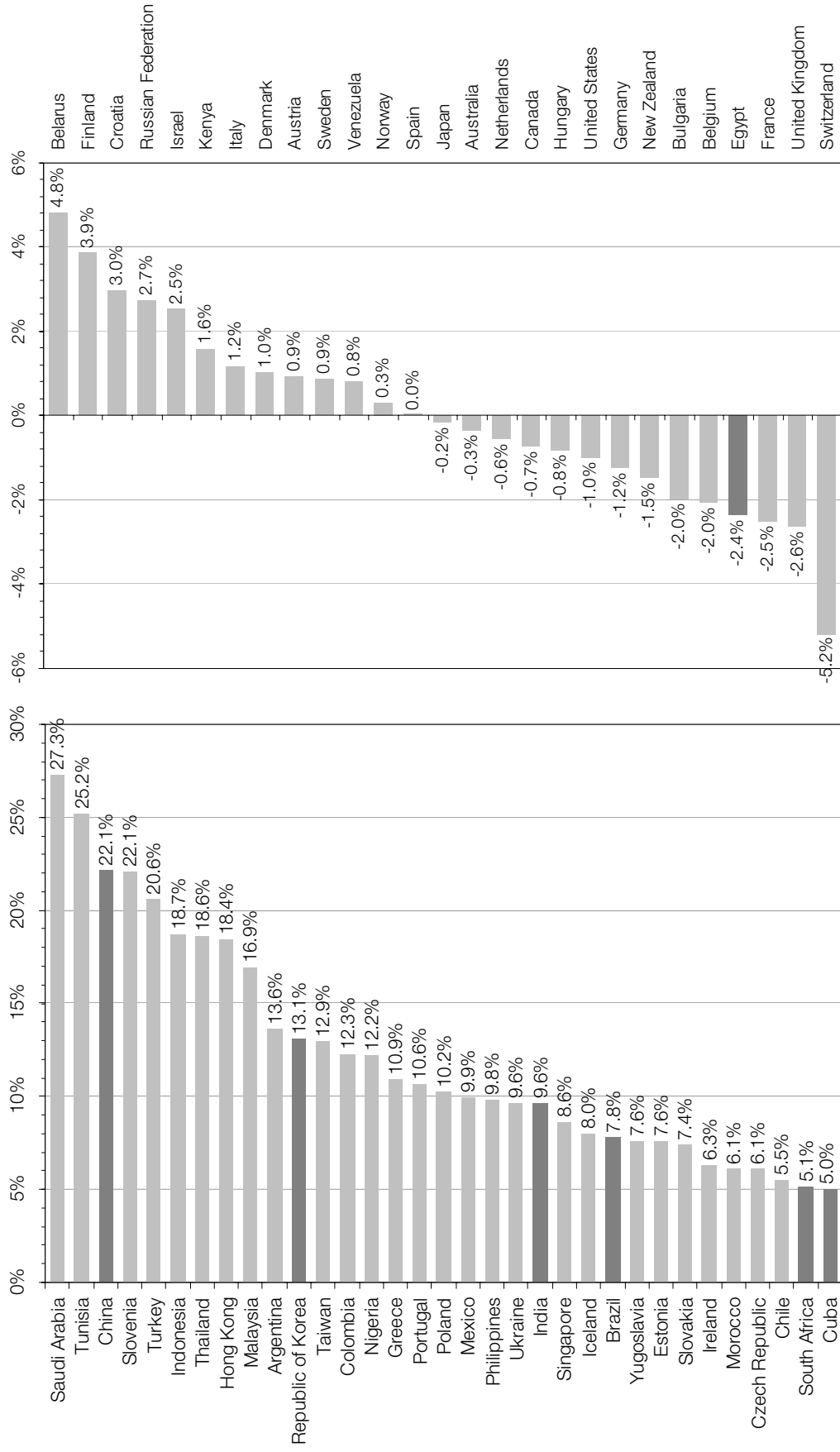


Figure 3 Top 60 countries by average yearly growth of papers in genomics, 1999-2002

Source: Compiled by Science-Matrix from data prepared by ISI Thomson.

3.2 Benchmarking leading countries and developing countries in genomics

This section aims to benchmark leading and developing countries using five evaluation criteria:

- Number of scientific papers in genomics in SCI Expanded
- Number of papers per capita
- Specialization index
- Average relative impact factor
- Average relative citations

The scientometric indicators are subsequently combined for a multicriteria benchmarking of leading and developing countries. This benchmarking is based on a period of 12 years, which, in turn, is divided into four three-year periods to examine the evolution of the domain for both leading and developing countries.

3.2.1 Number of scientific papers in genomics in SCI Expanded

Table I shows the number of papers published during the 12-year period studied by the 12 most prolific countries and the seven developing countries selected for the purposes of this study. The 12-year period is divided into four consecutive three-year periods. The number of papers published at the world level grew rapidly after the first three-year period and continued to grow afterwards, although at a much lower rate for the leading countries during the last two periods. Importantly, the output of many leading countries stabilized at more or less the same level as that observed during the 1994-1996 period. In the United States, the United Kingdom, France, Canada, the Netherlands, and Switzerland, the number of publications during the last period is actually lower than that of the preceding three years. Canada experienced rapid growth between the first and second periods, and its output peaked during the 1997-1999 period. For the developing nations, the growth experienced during the first two periods continues to this day, with the number of publications peaking during the 2000-2002 period. India started with a clear advantage during the first period, but was quickly surpassed by the phenomenal growth of China and the Republic of Korea, which now both publish more than India.

For the period of 2000-2002, China, the Republic of Korea, and India rank respectively 13th, 14th and 19th (see Table II). The scientific outputs of China and the Republic of Korea may surpass those of Switzerland and Sweden in the very near future: They will soon be a part of the 12 most active leading nations in terms of genome science papers published in the internationally most cited scientific journals.

Italy ranks 7th, just behind Canada, but the country is likely to be more productive than Canada over the next few years.

Table I Number of papers in genomics by leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	55,510	67,983	70,237	69,583	263,313
Japan	11,352	16,309	20,608	22,115	70,384
United Kingdom	11,318	14,500	16,151	16,113	58,082
Germany	9,035	12,529	15,373	15,855	52,792
France	8,271	11,241	12,523	12,190	44,225
Canada	5,862	7,483	7,967	7,866	29,178
Italy	3,912	5,704	6,958	7,378	23,952
Netherlands	3,264	4,254	4,772	4,735	17,025
Australia	3,060	4,048	4,822	4,924	16,854
Sweden	2,675	3,600	4,138	4,314	14,727
Spain	1,986	3,049	4,536	5,100	14,671
Switzerland	2,436	3,498	3,905	3,683	13,522
China	654	957	1,922	3,530	7,063
Republic of Korea	234	908	1,891	3,174	6,207
India	1,084	1,356	1,657	2,048	6,145
Brazil	594	824	1,301	1,828	4,547
South Africa	353	478	489	582	1,902
Egypt	89	121	172	191	573
Cuba	36	81	89	115	321
World	116,259	147,781	164,459	168,962	597,461

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table II Ranking of leading and developing countries according to their number of papers in genomics, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	1	1	1	1	1
Japan	2	2	2	2	2
United Kingdom	3	3	3	3	3
Germany	4	4	4	4	4
France	5	5	5	5	5
Canada	6	6	6	6	6
Italy	7	7	7	7	7
Netherlands	8	8	9	10	8
Australia	9	9	8	9	9
Sweden	10	10	11	11	10
Spain	12	12	10	8	11
Switzerland	11	11	12	12	12
China	21	20	17	13	15
Republic of Korea	32	22	18	14	19
India	17	18	20	19	20
Brazil	22	24	23	22	23
South Africa	26	28	34	36	32
Egypt	40	43	42	44	42
Cuba	52	49	53	50	52

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

3.2.2 Number of papers per capita

Measuring the number of papers per capita is one method of relating a country's scientific production to its size. One can see that among the 12 leading countries, several smaller European countries have a stronger per capita output than larger countries do (Table III). Switzerland and Sweden are clearly in a league of their own. The United Kingdom and Australia, which started with a relatively low level of productivity, increased their per capita output significantly over the 12 years. Globally, Canada's per capita output was highly similar to that of the United States and Australia. Most of the developing countries published less than the world average of nine papers per million inhabitants. Nonetheless, all experienced some growth during the 12-year period. It is important to emphasize the remarkable performance of the Republic of Korea. A highly populated developing country (48,289,037 inhabitants⁹), it began with only two papers per million inhabitants, surpassed the world average in the 1997-1999 period with 14 papers per million inhabitants, and, finally, finished with 22 papers per million inhabitants, for an overall average of 11 papers per million inhabitants, making it the only developing country to have achieved this benchmark. Due to their

⁹ CIA World Factbook 2003 : <http://www.cia.gov/cia/publications/factbook/index.html>

enormous population of more than one billion people, China and India are well below the world level, each with an average of one publication per million inhabitants.

Table III Number of papers in genomics per million inhabitants by leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Switzerland	116	163	180	169	157
Sweden	103	136	156	162	139
Netherlands	72	92	101	99	91
United Kingdom	65	83	91	90	82
United States	72	85	85	81	81
Canada	69	84	87	83	81
Australia	58	74	86	85	76
France	48	64	71	68	63
Germany	37	51	62	64	54
Japan	30	43	54	58	47
Italy	23	33	40	43	35
Spain	17	26	38	42	31
Republic of Korea	2	7	14	22	11
South Africa	3	4	4	5	4
Cuba	1	2	3	3	2
Brazil	1	2	3	3	2
Egypt	0.5	1	1	1	1
India	0.4	0.5	1	1	0.5
China	0.2	0.3	1	1	0.5
World	7	9	9	9	9

Source: Compiled by Science-Matrix from data prepared by ISI Thomson.

Table IV represents table III in terms of ranks. Most of the countries studied essentially maintained their ranking over the 12-year period. Of the leading countries, the United Kingdom managed to slightly improve its ranking, whereas Canada and the United States gradually dropped a few ranks. Canada went from 8th position during the first period to 11th position in 2000-2002, with an overall average rank of 10. The United States' drop in ranks was even more severe: it started in 5th position, only to finish in 13th, with an overall average rank of 9. Among the developing nations studied, the ranking generally remained stable, although Egypt and India did lose some ground, with Egypt starting in 49th position, only to finish in 56th place, with an overall average rank of 54, and India starting in 50th position and finishing in 57th position, with an overall average rank of 56. The losses of position, together with South Africa's, occurred between the first and second periods, showing that many countries entered the scientific race around 1993-1994. Obviously, the strong South Korean performance described in table III is reflected here in terms of rank. Korea started in 38th position and gradually improved its ranking to finish in 30th position, with an overall average rank of 32.

Table IV Ranking of leading and developing countries according to their per capita number of papers in genomics, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Switzerland	1	1	1	1	1
Sweden	2	2	2	2	2
Netherlands	7	6	7	7	7
United Kingdom	9	10	8	8	8
United States	5	8	11	13	9
Canada	8	9	9	11	10
Australia	10	11	10	9	11
France	15	15	15	16	15
Germany	16	16	17	17	17
Japan	18	18	18	18	18
Italy	19	20	20	21	20
Spain	22	22	21	22	21
Republic of Korea	38	33	32	30	32
South Africa	32	39	39	39	39
Cuba	42	41	41	41	41
Brazil	40	44	42	40	44
Egypt	49	54	55	56	54
India	50	56	56	57	56
China	56	58	57	55	57

Source: Compiled by Science-Matrix from data prepared by ISI Thomson.

3.2.3 Specialization index

The specialization index (SI) provides an assessment of the intensity of a country's scientific output in a given field, relative to its overall scientific output. Japan has become the clear leader in terms of specialization in genomics. The SI also shows that, in the past, Canada did not produce as much in genomics as one might have expected, given its share of world scientific output in general. Over the 12-year period examined here, Spain was last, save Canada, in terms of the SI (Table V). All the developing countries studied here improved their SI during the 12-year period. Nonetheless, only Cuba and the Republic of Korea came close to the world average, the rest of the developing countries being greatly under specialized in genomics. Cuba was the most specialized developing nation studied, with an average equal to that of Spain, and an SI above 1 during one period (1994-1996). In the case of the Republic of Korea, the SI grew steadily from a weak 0.49 in 1991-1993 to a 0.98 SI in 2000-2002, for an overall average of 0.90. This clearly shows that the Republic of Korea is actively making efforts to enter into the international genomic arena.

Table V Specialization index in genomics of leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Japan	1.19	1.27	1.36	1.40	1.32
Switzerland	1.31	1.38	1.29	1.20	1.29
Sweden	1.29	1.28	1.26	1.27	1.27
United States	1.22	1.23	1.21	1.20	1.21
France	1.25	1.25	1.19	1.15	1.20
Netherlands	1.20	1.15	1.14	1.10	1.15
Germany	1.01	1.06	1.07	1.07	1.06
Italy	1.04	1.05	1.06	1.04	1.05
United Kingdom	1.10	1.05	1.05	1.02	1.05
Australia	1.07	1.02	1.03	1.02	1.04
Canada	0.97	1.00	1.04	1.04	1.01
Spain	0.87	0.88	1.00	1.00	0.96
Cuba	0.85	1.08	0.92	0.93	0.96
Republic of Korea	0.49	0.78	0.86	0.98	0.90
Brazil	0.71	0.68	0.72	0.76	0.74
South Africa	0.53	0.62	0.59	0.68	0.61
India	0.39	0.42	0.48	0.55	0.46
China	0.36	0.33	0.41	0.53	0.45
Egypt	0.24	0.27	0.36	0.36	0.31
World	1.00	1.00	1.00	1.00	1.00

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table VI represents table V in ranks. Japan made a marked improvement on its initial position: it ranked 8th during the 1991-1993 period, moved to 5th in the 1994-1996 period and then to third. Switzerland, Sweden, and France started strong, but lost some rankings during the 12-year period studied. Canada managed to improve its ranking, starting in 20th position and finishing in 18th place, with an average rank of 19. Of the developing nations studied, most countries' ranks remained more or less stable during the 12-year period studied. Cuba was the most specialized developing country, sharing its 23rd position with Spain. Again, the Republic of Korea stood out from the pack, starting in 45th position in 1991-1993 and leaping to 24th in 2000-2002, with an average rank of 25.

Table VI Ranking of leading and developing countries in genomics according to their specialization index, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Japan	8	5	3	3	2
Switzerland	1	3	4	8	4
Sweden	2	4	6	5	6
United States	6	7	7	7	7
France	3	6	9	10	9
Netherlands	7	11	11	13	12
Germany	18	14	14	15	15
Italy	15	15	15	17	16
United Kingdom	10	16	17	20	17
Australia	12	17	19	19	18
Canada	20	20	18	18	19
Spain	24	25	21	21	23
Cuba	26	13	24	26	23
Republic of Korea	45	29	27	24	25
Brazil	30	35	34	38	35
South Africa	40	40	43	43	44
India	51	52	50	50	51
China	52	56	54	51	52
Egypt	56	59	57	59	59

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

3.2.4 Average relative impact factor

The average relative impact factor (ARIF) is used to evaluate the expected impact of papers from each country compared to other papers in genomics at the world level. This indicator provides a proxy for the quality of the journals in which papers are published: the higher the index value, the higher the average quality of a journal is. For instance, the United States and Switzerland both have papers in genomics whose expected impact is considerably higher than that of other countries (by 19% and 16% respectively) (Table VII). They are followed by the United Kingdom and the Netherlands, which both published genomics papers in journals that were cited 7% more than the world average in this discipline. Canada published in journals that were cited 6% more than the world average for genomics. Although the impact factor of Canadian papers increased steadily over the period, the ARIF of the United Kingdom grew faster still, which explains why Canada slid from 3rd position in the first period to 4th in the second, and 5th in the last two three-year periods (Table VIII). The Netherlands was the most improved for its scientific impact over the period studied (from 12th to 4th).

Looking at the selected developing countries over the period as a whole, South Africa published in the journals most often cited. However, South African genome science did not reach the average world level of scientific impact. Also noteworthy, Brazil, Cuba, and India significantly improved their ARIF scores between 1991-1993 and 2000-2002 (Brazil, 0.61 to 0.78; Cuba, 0.64 to 0.75; India, 0.46 to 0.58).

Table VII Average relative impact factor in genomics of leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	1.18	1.19	1.20	1.19	1.19
Switzerland	1.14	1.15	1.19	1.16	1.16
Netherlands	0.96	1.05	1.10	1.13	1.07
United Kingdom	1.00	1.02	1.09	1.12	1.07
Canada	1.01	1.05	1.07	1.09	1.06
France	0.96	0.96	1.02	1.05	1.00
Germany	0.93	0.96	0.98	1.02	0.98
Australia	0.92	0.94	0.96	0.98	0.95
Sweden	0.90	0.95	0.97	0.97	0.95
Italy	0.85	0.92	0.94	0.96	0.93
Spain	0.87	0.92	0.94	0.95	0.93
Japan	0.87	0.87	0.87	0.87	0.87
South Africa	0.78	0.83	0.74	0.84	0.80
Republic of Korea	0.80	0.80	0.70	0.76	0.75
Brazil	0.61	0.73	0.74	0.78	0.74
Cuba	0.64	0.78	0.61	0.75	0.71
Egypt	0.59	0.74	0.69	0.64	0.67
China	0.55	0.52	0.49	0.57	0.54
India	0.46	0.48	0.54	0.58	0.53
World	1.00	1.00	1.00	1.00	1.00

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table VIII Ranking of leading and developing countries in genomics according to their average relative impact factor, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	1	1	3	2	1
Switzerland	2	2	4	3	3
Netherlands	12	3	6	4	4
United Kingdom	7	8	7	5	6
Canada	5	4	10	8	8
France	11	12	11	10	11
Germany	14	13	15	13	14
Australia	15	18	18	16	15
Sweden	17	14	17	17	16
Italy	23	20	20	18	19
Spain	20	21	22	20	20
Japan	19	28	26	29	29
South Africa	37	33	40	32	35
Republic of Korea	33	35	46	42	41
Brazil	47	44	41	40	42
Cuba	43	38	53	44	47
Egypt	50	43	47	53	51
China	52	55	57	57	56
India	54	57	54	56	57

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

3.2.5 Average relative citation

Whereas the impact factor provides a measure of the average number of citations received by journals, and thus an expected citation score, the average relative citation is an indicator of the number of times papers published by a country are actually cited, relative to the world average. Again, a score above one denotes that a country's genomics papers are cited more often than the average paper in genomics.

Although the United States had the highest number of *expected citations* (i.e.: impact factor), it is Switzerland that had the greatest number of *observed citations* per paper on average (Table IX). On average, papers by the United States, the Netherlands, and the United Kingdom were also cited significantly more often than those of other countries. Those by Canada, Germany, France, Sweden, and Australia were also, on average, cited more often than the world average. Australia has increased its average number of citations per paper steadily and might overtake Canada in the near future. Over the 12-year period, Canada ranked 10th in terms of ARC, well behind the United Kingdom (with a rank of 5). Importantly though, Germany is rapidly closing the gap with Canada (Table X). For the developing countries studied, as in the case of the ARIF, none show an average relative citation index higher than one. Unlike the case of the ARIF, however, the Republic of Korea did not occupy 2nd

place among developing countries in terms of its average relative citation index; this position belongs to Cuba, with South Korea pushed into 3rd place. The South African and Cuban ARCs grew steadily over the 12-year period studied. This is reflected by their rankings, which also grew steadily. South Africa occupied 1st place among the seven developing countries for this index (with a value of 0.75 for the 12-year period studied), just like it did for the ARIF. Cuba was 2nd, with an average relative citation index of 0.63 for the 12-year period studied. The Republic of Korea's ARC, as with the ARIF, decreased during the period studied. This was also reflected by its rank, which dropped nine positions during the 12 years. Brazil did not perform as well with this index as it did with the ARIF. Brazil's ARC jumped by 0.19 between 1991-1993 and 1994-1996, to finally drop back to 0.55 during the 2000-2002 period. This bell curve distribution is also observed with Brazil's ranking. Brazil started in 47th place, progressed to 42nd, continued to 38th, only to finish in 50th place in 2000-2002. Egypt, China, and India behaved very poorly as far as this index was concerned. Indeed, they occupied the 53rd, 54th and 58th positions respectively.

Table IX Average relative citations in genomics of leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Switzerland	1.19	1.32	1.35	1.37	1.32
United States	1.23	1.24	1.25	1.27	1.25
Netherlands	1.17	1.20	1.21	1.28	1.22
United Kingdom	1.14	1.15	1.21	1.26	1.20
Canada	1.02	1.07	1.12	1.10	1.08
Germany	0.99	1.04	1.03	1.11	1.05
France	1.00	1.04	1.03	1.06	1.03
Sweden	0.98	1.06	1.02	1.03	1.03
Australia	0.91	0.98	1.01	1.09	1.01
Italy	0.80	0.93	0.91	0.91	0.90
Spain	0.71	0.77	0.88	0.92	0.85
Japan	0.86	0.82	0.83	0.85	0.84
South Africa	0.67	0.80	0.67	0.84	0.75
Cuba	0.54	0.85	0.48	0.72	0.67
Republic of Korea	0.69	0.53	0.65	0.64	0.63
Brazil	0.50	0.69	0.66	0.55	0.60
Egypt	0.50	0.53	0.53	0.47	0.50
China	0.49	0.45	0.47	0.51	0.49
India	0.25	0.30	0.36	0.44	0.36
World	1.00	1.00	1.00	1.00	1.00

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table X Ranking of leading and developing countries in genomics according to average relative citations, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Switzerland	5	3	2	2	2
United States	3	4	4	4	3
Netherlands	6	6	6	3	4
United Kingdom	7	8	5	5	5
Canada	10	12	9	12	10
Germany	13	14	15	11	12
France	12	15	16	17	15
Sweden	15	13	17	18	16
Australia	19	20	18	14	17
Italy	28	22	22	22	20
Spain	31	37	25	21	24
Japan	22	31	30	25	27
South Africa	35	36	36	29	37
Cuba	43	26	51	36	41
Republic of Korea	33	50	41	42	44
Brazil	47	42	38	50	46
Egypt	46	51	50	54	53
China	49	54	53	53	54
India	56	58	58	55	58

Source: Compiled by Science-Matrix from data prepared by ISI Thomson.

3.2.6 Multicriteria analysis

The multicriteria ranking provides an overall assessment of the 60 leading countries in genomics. The criteria considered in the multicriteria ranking were number of papers, number of papers per capita, specialization index, average relative impact factor, and average relative citations. During the 12-year period considered here, the United States and Switzerland were the clear winners (Table XI). The Netherlands were 3rd, and the 4th place was occupied by the United Kingdom. France was 8th, Sweden 6th, and Canada 7th. Canada progressed during the period studied: it was in 10th place during the 1991-1993 period, moved to the 7th in 1994-1996, to 6th during 1997-1999, before finally dropping into 8th position in 2000-2002, for an overall average rank of 7. Most countries' positions remained relatively stable during the 12 years covered by this study, although some countries managed to improve their positions, like Denmark, which managed to gain six positions during the fourth period to reach 6th place in 2000-2002, placing it 10th overall.

For the developing countries chosen for this study, the Republic of Korea was 1st with its 28th place and South Africa was 2nd in 36th place overall. South Africa was followed closely by Brazil (3rd) in 38th place. Cuba (4th) was further behind in 43rd place, followed China (5th) in 51st place, India (6th) in 54th position and, finally, Egypt (7th) near the bottom of the ranking, in 57th position.

Table XI Multicriteria ranking of leading and developing countries in genomics, 1991-2002

Rank	Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
1	United States	1	2	2	2	1
2	Switzerland	2	1	1	1	2
3	Netherlands	4	3	3	3	3
4	United Kingdom	3	6	4	4	4
5	Finland	5	4	5	5	5
6	Sweden	6	4	7	7	6
7	Canada	8	7	6	8	7
8	France	6	8	8	9	8
9	Belgium	9	9	9	10	9
10	Denmark	10	11	10	6	10
11	Germany	13	10	12	11	11
12	Iceland	16	12	11	13	12
13	Israel	12	13	13	12	13
14	Australia	13	14	14	13	14
15	Austria	10	17	15	16	15
16	Japan	15	15	16	15	16
17	Italy	18	15	17	17	17
18	Norway	17	18	20	19	18
19	Spain	19	19	18	18	19
20	Ireland	22	21	18	20	20
21	New Zealand	20	19	21	21	21
22	Portugal	26	25	22	23	22
23	Singapore	21	24	24	28	23
24	Taiwan	23	27	27	31	24
25	Kenya	28	26	27	30	25
26	Estonia	33	42	32	25	26
27	Hungary	30	37	24	22	26
28	Republic of Korea	36	33	30	26	28
29	Czech Republic		27	26	29	29*
30	Greece	28	34	32	24	29
31	Hong Kong	31	29	29	27	31
32	Saudi Arabia	46	30	32	34	32
33	Philippines	35	40	23	36	33
34	Thailand	26	38	35	31	33
35	Tunisia	34	23	31	44	35
36	South Africa	32	35	38	33	36
37	Colombia	25	22	43	48	37
38	Brazil	37	39	36	37	38
39	Mexico	24	36	39	44	38
40	Argentina	40	41	37	42	40
41	Slovenia	41	51	47	35	41
42	Poland	38	45	39	39	42
43	Cuba	44	30	50	38	43
44	Croatia	45	46	39	46	44
45	Venezuela	38	49	45	43	44
46	Chile	47	50	46	39	46
47	Slovakia		46	48	41	47*
48	Indonesia	52	30	51	46	48
49	Turkey	50	44	44	48	49
50	Russian Federation	42	48	49	50	50
51	China	50	54	54	51	51
52	Morocco	55	43	42	56	51
53	Bulgaria	48	52	53	52	53
54	India	49	53	54	53	54
55	Yugoslavia	43	56	59	58	55
56	Malaysia	53	57	52	55	56
57	Egypt	54	55	56	57	57
58	Belarus	57	58	57	60	58
59	Ukraine	58	59	58	59	59
60	Nigeria	56	60	60	54	60

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

* The global scores for the Czech and the Slovak republics are based on the last nine years.

The leading developing country in genomics, the Republic of Korea, is one of the fastest growing countries on the multicriteria index; it gained 12 positions during the four periods studied. It started in 38th position in 1991-1993 and finished in 26th place in 2000-2002. Most developing countries improved their positions on the multicriteria index over the 12-year time span, although China, India, and Egypt's positions (51st, 54th and 57th place respectively) were relatively stable. South Africa and Brazil ranked close together in 36th and 38th place.

Because of its internal construction, the multicriteria index can be favourable to small countries, because it is easier for countries with low number of papers to maintain an overall strong impact factor and index of citations. This helps to explain the strong positions for countries like Iceland, which scored 1st on the ARIF index and finished in 12th position on the multicriteria index, ahead of Australia, Japan, Italy, and Spain. The high positions for Finland (5th), Belgium (9th), Denmark (10th), Israel (13th), and Norway (18th) can also be explained by these mechanisms. Nevertheless, the multicriteria index remains an efficient holistic index that permits the overall comparison between countries.

3.2.7 International and national collaboration in and by developing countries

This section aims to provide a quantitative overview of international and national scientific collaboration trends in genomics in and by the developing countries selected for this study. Figure 4 illustrates the proportion of international and national collaboration in the domain. Canada is used as a point of reference.

Overall, between 1991 and 2002, Canada and the developing countries studied, proportionally published more genomic papers with international collaborators (more than 40% of the genomics papers) than with national collaborators. This was not the case for the Republic of Korea. In fact, from 1995 to 2002, there was more collaboration in genomics between national counterparts in the Republic of Korea, than there was between Korean institutions and international partners (e.g.: in 2002, national collaboration accounted for 47.7% of papers versus international collaboration at 31.6%). The same collaboration dynamic can be observed in Brazil and China in the years that followed; 1999-2002 data suggest that, proportionally, there was a trend for more national collaboration.

Not only did India have the lowest rate of international collaboration over the 12-year period studied, but also one of the lowest national collaboration rates. In fact, in Indian genome science, international collaboration represents 23.2% and national collaboration 26.1%. This indicates that, proportionally, Indian researchers, in comparison with other developing countries, tend to publish papers individually rather than in collaboration with national or international colleagues. Egypt has a fairly high international collaboration rate (74.6% in 2002), but also the lowest national collaboration rate (11.1% in 2002), which demonstrates Egypt's scientific dependence on international activity in genome science. South Africa also experienced a low, and decreasing, rate of national collaboration.

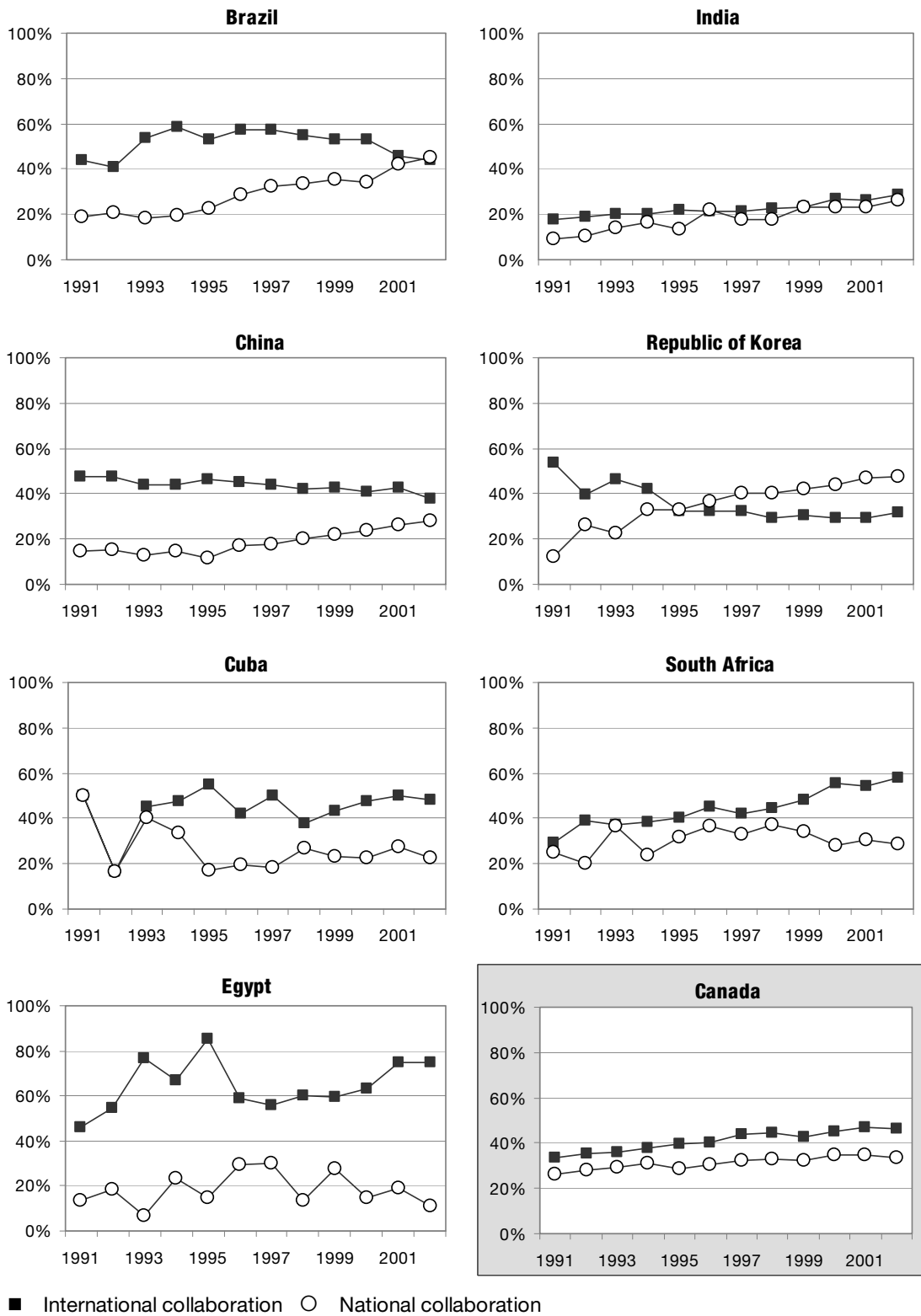


Figure 4 International and national collaboration rates of developing countries and Canada in genomics, 1991-2002

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

3.2.8 Main countries that collaborate with developing countries in genomics

Between 1991 and 2002, taken as a group, the seven developing countries principally collaborated with the leading countries in genomics: United States (50.2%), Japan (12.7%), United Kingdom (12.2%), Germany (8.3%), France (7.0%), and Canada (4.4%). This distribution is about the same as the share of the publications of these developed countries in genomics. However, when the seven developing countries are considered individually, one can see that each country has a specific collaboration pattern.

Besides the six leading countries in genomics, it is interesting to look at other existing international networks of collaboration. Brazil collaborates with Argentina (4.1%), the Netherlands (4.0%), Italy (3.8%), Belgium (3.6%), and Spain (3.4%). The three most important international institutions to collaborate with Brazil are Harvard University (United States), the Centers for Disease Control and Prevention (United States), and the Institut Pasteur (France).

Of China's scientific output, 9.4% is produced in collaboration with Hong Kong, 4.2% with Sweden, and 3.9% with Australia. China's three most important institutional collaborators are the University of Hong Kong (Hong Kong), the Chinese University of Hong Kong (Hong Kong), and the National Cancer Institute (United States).

Cuba is the only developing country whose main collaborator is not the United States. In fact, Cuba's principal international collaborators are from France (21.2%) and Spain (17.8%). Cuba also collaborates to 13% with its neighbour, Mexico (19 papers). The three international institutions that have collaborated most with Cuba are the Instituto Plitécnico Nacional (Mexico), the Consejo Superior de Invesigaciones Científicas (Spain), and the Düsseldorf University Hospital (Germany).

Again, besides the most common international collaborators, Egypt has collaborated with Finland (5.1%), Italy (4.8%), and the Netherlands (3.2%). Main international institutional collaborators are the University of Texas (United States), the University of Helsinki (Finland), the University of London (United Kingdom), and the USDA Agricultural Research Service (United States).

India's international collaborators are also largely among the leading countries in genomics. Main institutional co-workers are the University of Texas (United States), the National Cancer Institute (United States), and the University of London (United Kingdom).

The Republic of Korea is the developing country that has published most with the United States, both proportionally and in terms of the absolute number of papers published, (66.1%; 1289 papers). South Koreans have also collaborated most with Japan (23.8%). The Republic of Korea's main institutional collaborators are the National Cancer Institute (United States), the University of Texas (United States), and the University of Tokyo (Japan).

Not surprisingly, South Africans have tended to collaborate with Commonwealth countries: the United Kingdom (27.0%), Australia (7.2%), and Canada (6.8%). Main institutional collaborators are the University of London (United Kingdom), the University of Texas (United States), and the University of Oxford (United Kingdom).

In terms of the proportion of all papers published in collaboration with international partners, the developing countries that collaborated most with Canada were Brazil (5.7%) and Cuba (5.5%); in terms of the absolute number of papers published in collaboration, they were Brazil (131 papers) and China (112 papers).

Table XII Main countries that collaborate with developing countries in genomics, 1991-2002

Country	Brazil	China	Cuba	Egypt	India	Republic of Korea	South Africa
United States	50.5%	44.3%	15.1%	48.5%	47.3%	66.1%	45.8%
Japan	4.8%	15.6%	2.1%	6.2%	11.7%	23.8%	5.1%
United Kingdom	14.6%	10.4%	7.5%	11.0%	14.2%	4.6%	27.0%
Germany	8.7%	7.7%	15.1%	11.5%	13.2%	3.7%	11.6%
France	12.0%	5.5%	21.2%	6.7%	5.4%	2.4%	9.5%
Canada	5.7%	3.8%	5.5%	3.5%	3.9%	3.4%	6.8%
Australia	1.9%	3.9%	1.4%	0.5%	2.9%	1.7%	7.2%
Hong Kong	0.2%	9.2%	0.0%	0.5%	0.6%	0.2%	0.9%
Sweden	1.6%	4.2%	7.5%	1.9%	2.2%	2.3%	3.9%
Italy	3.8%	1.3%	7.5%	4.8%	2.9%	1.3%	6.2%
Netherlands	4.0%	2.0%	2.1%	3.2%	2.4%	0.9%	6.2%
Spain	3.4%	0.7%	17.8%	1.1%	1.4%	0.8%	2.9%
Belgium	3.6%	1.0%	1.4%	0.3%	2.0%	0.4%	3.6%
Israel	1.2%	1.1%	1.4%	1.9%	1.8%	0.8%	2.9%
Switzerland	2.2%	0.8%	2.7%	1.1%	1.4%	0.5%	2.5%
Denmark	0.9%	1.2%	0.7%	1.9%	1.6%	1.1%	2.9%
Argentina	4.1%	0.2%	2.7%	1.6%	0.3%	0.3%	0.2%
Taiwan	0.2%	2.1%	0.0%	0.5%	0.8%	1.6%	0.9%
Finland	0.6%	0.7%	0.7%	5.1%	0.4%	1.2%	1.8%
Total collaboration (n)	2,317	2,975	146	373	1,424	1,951	867

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4 Health Biotechnology at the International Level

Like the section on genomics, the section on health biotechnology presents data on the global rate of growth of scientific papers written in the domain of health biotechnology at the world level (Section 4.1). It subsequently benchmarks the scientific output of the seven developing countries in the domain against that of other leading countries, including Canada (Section 4.2).

4.1 Global trends in health biotechnology

The number of scientific papers in health biotechnology remained more or less stable during the 1991-2002 period, reaching a peak in 1998 with slightly more than 13,000 papers (Figure 5). The number of papers went from about 10,000 in 1991 to about 12,000 in 2002, an increase of approximately 1% over the 12-year period. The proportion of health biotechnology papers in the SCI Expanded database slightly decreased over the period studied, dropping from 1.8% in 1991 to 1.6% in 2002, with its peak in 1994 at 1.9%. After examining these numbers, it is safe to assume that this research sector is stable and has reached a plateau in its expansion.

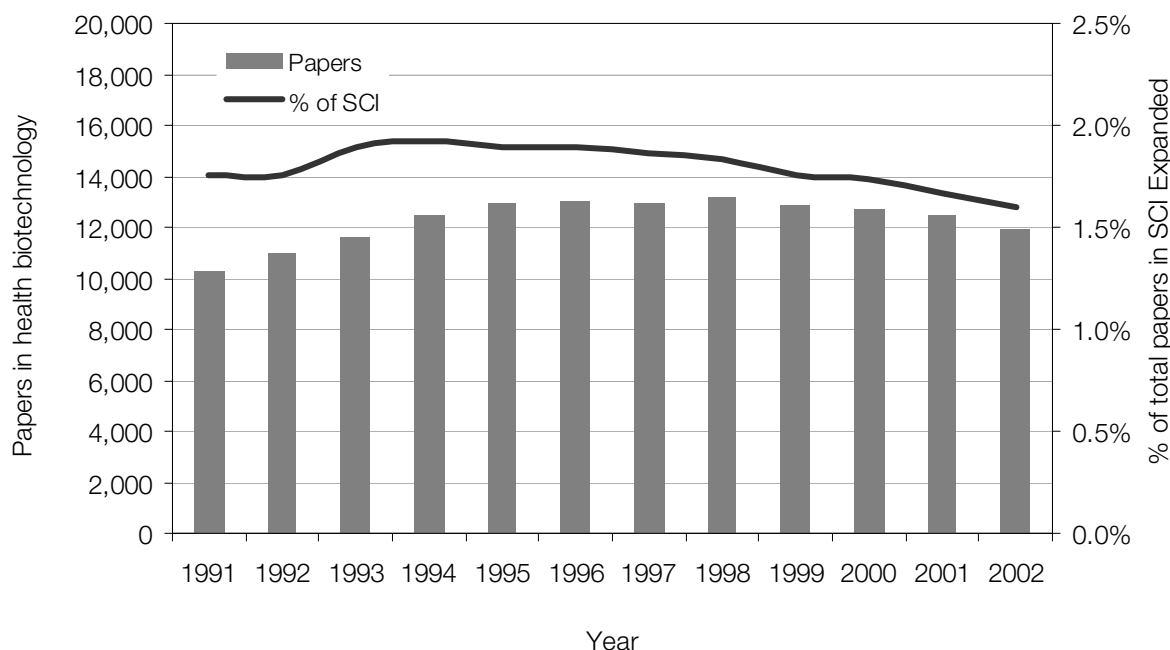


Figure 5 Papers in health biotechnology in SCI Expanded, 1991-2002

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

During the last 12 years, Canada's output of papers in health biotechnology has been consistent with the place it occupies among the G7 countries (Figure 6). As was the case in genome science, the G7 economic countries are also the G7 health biotechnology countries. Data presented in Section 4.2 show that during the last 12 years, when considering four three-year periods, Canada consistently ranked 6th among the 12 leading countries. In fact, the ranking of the seven leading countries was highly stable, with everyone keeping the same rank. It is important to mention the overwhelming

performance of the United States: it occupied the 1st position with 59,865 publications, a number that was significantly higher than the 18,332 publications produced by Japan, who ranked 2nd overall.

The 12 leading genomics countries also lead the way in health biotechnology. As in genomics, there is a discontinuity in the number of health biotechnology papers published by the 12 most active countries: the number of papers produced by countries ranking lower than 12th place, occupied by Spain, is substantially lower than that produced by the 12 leaders (Figure 6). However, the Republic of Korea's publication performance still compares to that of Spain (two positions behind Spain, with Korea having produced 2,046 publications and Spain 3,220). Not far behind, in 16th position, is India with 1,722 publications. China (1,621 publications) and Brazil (1,186 publications) follow closely in 19th and 22nd position respectively. Again, South Africa is next, albeit far behind the countries previously discussed. It occupies 30th place, with 475 publications. Cuba is even further behind, in 40th place, with 216 publications, which means that it produces an average of only 18 publications per year. Finally, Egypt is in 43rd position, with only 159 publications.

Figure 7 presents the most recent yearly growth trends in health biotechnology papers, as measured in 1999-2002. Most of the seven countries central to this study experienced a relatively high growth rate in terms of health biotechnology publications, with growth rates superior to that of the 12 leading countries in terms of absolute number of papers published. Cuba and Turkey share the 1st position, having the highest average growth rate, 25.2%, in the domain. Singapore follows with an average growth of 22.6%.

China also ranks high, in 4th position, with a growth rate of 19.6% (compared to its 19th position in absolute number of papers published). Like China, the Republic of Korea experienced a slightly slower growth rate in health biotechnology (11.8%) than in genomics (13.1%). India grew at about the same rate in both domains and ranked 10th in 1999-2002 (10.8% in health biotechnology and 9.6% in genomics).

It is noteworthy that South Africa's (7th in 1999-2002) growth rate in health biotechnology was much higher than that observed in genomics. In fact, South Africa's annual growth in health biotechnology publications was 7.4% higher than that measured in genomics. Brazil's publications also grew 2.6% faster in health biotechnology than they did in genomics, and the country ranks of 11th in health biotechnology, just behind India.

The Republic of Korea and India's positions are extremely strong, since both managed to have a relatively high growth rate (10%) and a respectable number of publications. In fact, it is often more difficult for a country to have a strong growth rate when it publishes many papers. Inversely, small annual outputs and variations can disproportionately affect growth. For example, Egypt has a negative average growth, (-6%) although its absolute number of papers published remained relatively stable (between 60 and 68 papers a year). As in genomics, the 12 leaders in terms of the absolute number of papers published also occupy the bottom positions of this ranking, meaning that their scientific output in health biotechnology is also saturated in terms of growth.

Genomics and Health Biotechnology in Seven Developing Countries

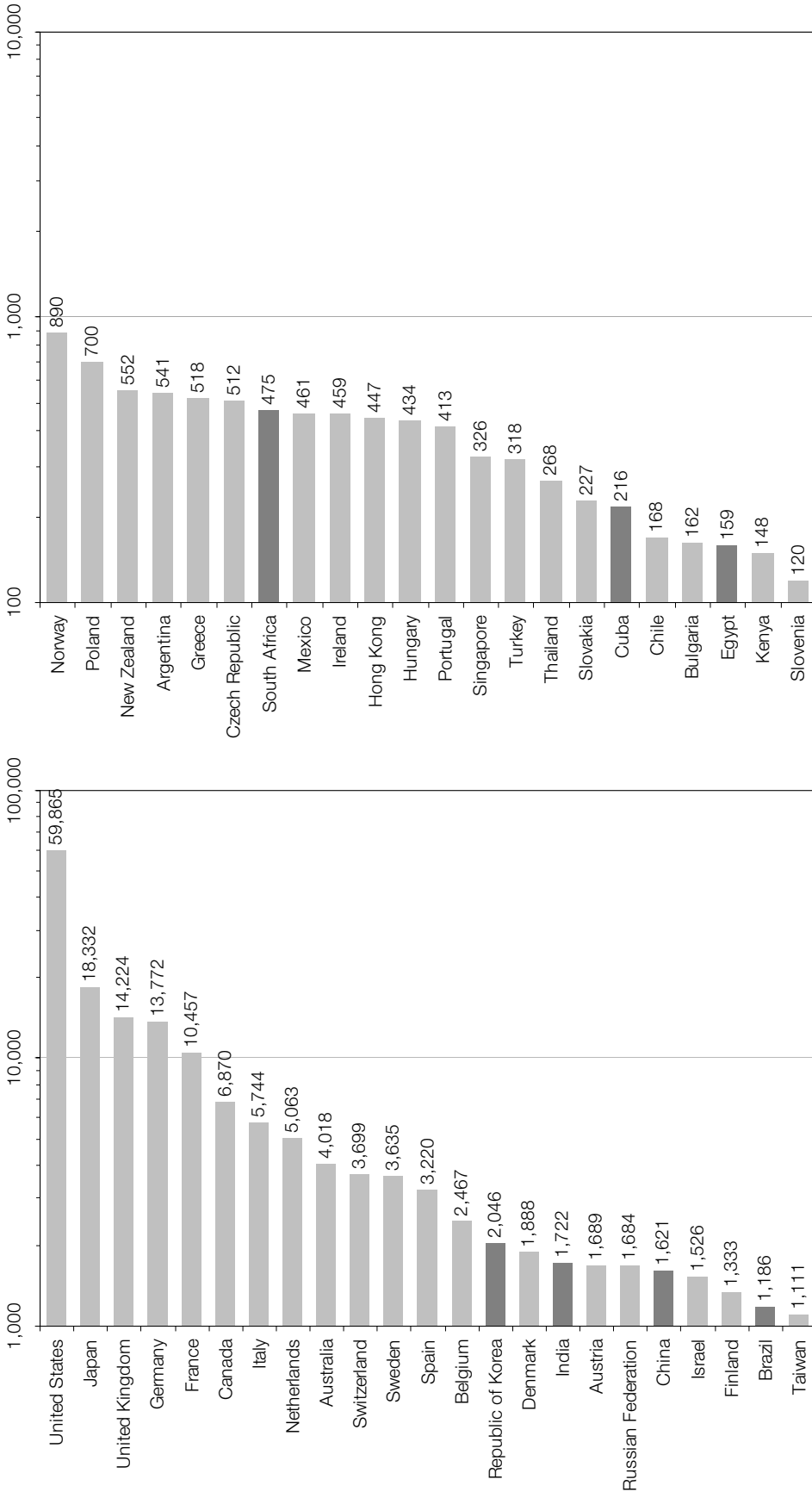


Figure 6 Top 45 countries by number of papers in health biotechnology (log scale), 1991-2002

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Genomics and Health Biotechnology in Seven Developing Countries

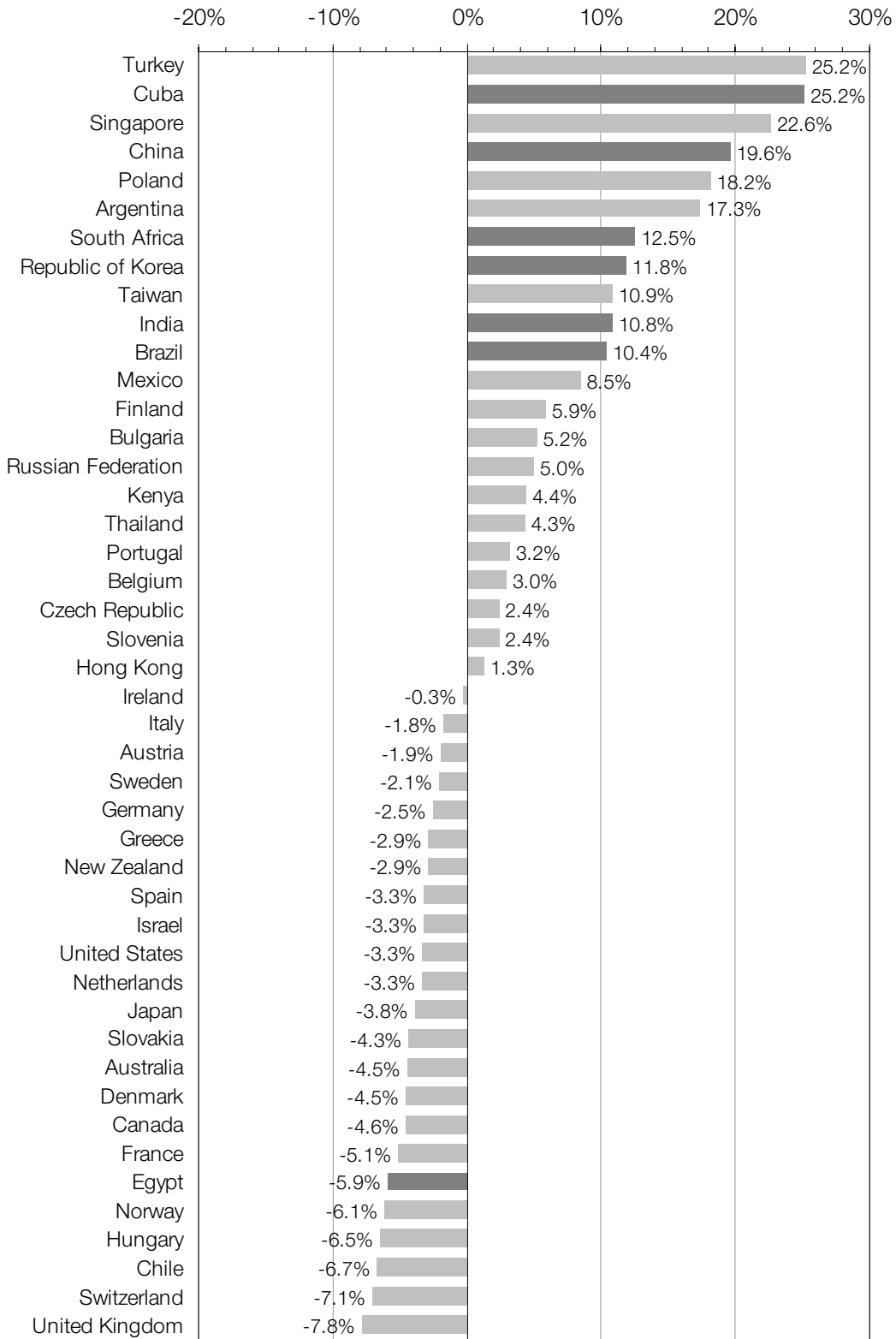


Figure 7 Top 45 countries by average yearly growth of papers in health biotechnology, 1999-2002

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4.2 Benchmarking leading countries and developing countries in health biotechnology

This section aims to benchmark leading and developing countries in health biotechnology, using five evaluation criteria:

- Number of scientific papers in health biotechnology in SCI Expanded
- Number of papers per capita
- Specialization index
- Average relative impact factor
- Average relative citations

The factors are subsequently combined to produce a multicriteria benchmarking of leading and developing countries. The benchmarking is based on a 12-year period, which in turn is divided into four three-year periods to examine and benchmark the evolution of the domain in the leading and developing countries studied.

4.2.1 Number of scientific papers in health biotechnology in SCI Expanded

Table XIII shows the number of papers published during each of the four three-year periods and, overall, during the 12-year period covered by this study, specifically, those published by the 12 most prolific countries and the seven developing countries chosen for the purposes of this study. The number of papers published grew rapidly at the world level after the first period. The United States and France reached their peak in the 1994-1996 period, while all the other prolific countries continued to increase their number of publications until the 1997-1999 period, where they reached their peak. The United States and France reached their peak in 1994-1996, and all of the other prolific countries continued to increase their number of publications after that, reaching their peak in 1997-1999. The 2000-2002 period witnessed a decline in the number of publications in all the leading countries, except Spain, which has sustained permanent growth since 1991. In the case of developing countries, the growth experienced during the first period has continued to this day, with the number of publications reaching a peak in the 2000-2002 period. Again, India was the clear leader in the first period, but was quickly surpassed by the Republic of Korea and China, both of which are now publishing more than India.

Table XIII Number of papers in health biotechnology by leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	14,224	16,273	15,350	14,018	59,865
Japan	3,890	4,779	5,008	4,655	18,332
United Kingdom	3,264	3,772	3,810	3,378	14,224
Germany	2,795	3,362	3,819	3,796	13,772
France	2,345	2,844	2,788	2,480	10,457
Canada	1,535	1,822	1,846	1,667	6,870
Italy	1,127	1,488	1,583	1,546	5,744
Netherlands	1,144	1,316	1,380	1,223	5,063
Australia	850	1,018	1,121	1,029	4,018
Switzerland	843	961	983	912	3,699
Sweden	767	898	1,017	953	3,635
Spain	436	737	1,007	1,040	3,220
Republic of Korea	113	340	663	930	2,046
India	283	371	463	605	1,722
China	165	237	401	818	1,621
Brazil	141	228	316	501	1,186
South Africa	100	101	122	152	475
Cuba	28	55	59	74	216
Egypt	30	36	45	48	159
World	32,860	38,451	39,001	37,131	147,443

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table XIV ranks the 12 leading countries and seven developing countries studied according to their number of publications in health biotechnology during the four three-year periods and for the 12-year period as a whole. As one can see, for the six most productive countries, the ranks remained very stable over the whole period. However, the smaller contenders among the 12 most productive countries demonstrated more volatility. For instance, Switzerland ranked 10th initially, then moved to the 12th rank in 1997-1999, to finally drop to 13th place in 2000-2002. Again, the rising star is Spain, which started in 13th position, moved to 11th in 1997-1999 and to 9th in 2000-2002. Among the developing countries, the Republic of Korea gained remarkable ground, starting in 25th position in 1991-1993 and finishing in 12th in 2000-2002 ahead of Switzerland, with an overall rank of 14 over all four periods. China's growth is as impressive: starting in 22nd place in 1991-1993, it finished an amazing 14th in 2000-2002, with an overall average of 19. India, Brazil, Egypt, and Cuba all steadily improved their position during the 12-years studied. The only developing country that showed a clear ranking decrease was South Africa, starting in 26th position, only to finish in 33rd place, with an overall average of 30.

Table XIV Ranking of leading and developing countries according to their number of papers in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	1	1	1	1	1
Japan	2	2	2	2	2
United Kingdom	3	3	4	4	3
Germany	4	4	3	3	4
France	5	5	5	5	5
Canada	6	6	6	6	6
Italy	8	7	7	7	7
Netherlands	7	8	8	8	8
Australia	9	9	9	10	9
Switzerland	10	10	12	13	10
Sweden	11	11	10	11	11
Spain	13	12	11	9	12
Republic of Korea	25	19	13	12	14
India	17	18	17	16	16
China	22	23	20	14	19
Brazil	23	24	22	18	22
South Africa	26	31	34	33	30
Cuba	41	38	40	39	40
Egypt	40	42	42	43	43

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Measuring the number of papers per capita is one way of relating a country's scientific production to its size. One can see that among the 12 leading countries, several smaller European countries have a stronger per capita output than larger countries do (Table XV). Again, Switzerland and Sweden are clearly in a league of their own. Globally, Canada has a per capita output that is highly similar to that of the United States and the United Kingdom. Most developing countries publish less than the world average of two papers per million inhabitants. Nonetheless, all experienced some growth during the 12-year period. Again, it is important to emphasize the remarkable performance of the Republic of Korea. A highly populated developing country, it started with only one paper per million inhabitants, surpassed the world average in the 1994-1996 period with three papers per million inhabitants and, finally, finished with seven papers per million inhabitants, for an overall average of four papers per million inhabitants, making it the only developing country studied to have surpassed the world average benchmark. Cuba is the only other developing country to have reached the world average. Because of the enormous size of their respective populations (more than one billion people), China and India are well below the world level, with an average close to 0 (0.12) publications per million inhabitants. Egypt's performance is also not very significant (less than 0.5

publications per million inhabitants). This is probably due to its relatively large population (74,718,797¹⁰ people).

Table XV Number of papers in health biotechnology per million inhabitants by leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Switzerland	40	45	45	42	43
Sweden	29	34	38	36	34
Netherlands	25	28	29	26	27
United Kingdom	19	22	22	19	20
Canada	18	21	20	18	19
United States	18	20	19	16	18
Australia	16	19	20	18	18
France	14	16	16	14	15
Germany	12	14	16	15	14
Japan	10	13	13	12	12
Italy	7	9	9	9	8
Spain	4	6	8	9	7
Republic of Korea	1	3	5	7	4
Cuba	1	2	2	2	2
South Africa	1	1	1	1	1
Brazil	0.3	0.5	1	1	1
Egypt	0.2	0.2	0.2	0.2	0.2
India	0.1	0.1	0.2	0.2	0.2
China	0.0	0.1	0.1	0.3	0.1
World	2	2	2	2	2

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table XVI represents table XV in terms of ranks. Of the six leading countries, only Switzerland and Sweden managed to maintain their 1st and 2nd place. The Netherlands went from 3rd to 5th place, for an overall average of 4th position. The United Kingdom fell from 6th to 9th place, for an overall average of 8th position. Canada dropped from the 9th position during the first period to the 11th position in 2000-2002, for an overall average rank of 9. The United States' drop in rank was even more severe: it started in 7th position, only to finish 12th, for an overall average rank of 10. Contrary to the situation in genomics, the ranking was generally more variable in the developing nations chosen for the study. All the developing countries, except Korea, dropped in position between the first and second period, showing, once again, that many countries entered the scientific race around 1993-1994.

Of the developing countries, South Africa experienced the most severe drop in ranking: it fell from 33rd to 39th position, for an overall average rank of 38. Obviously, the strong Korean performance

¹⁰ CIA World Factbook 2003 : <http://www.cia.gov/cia/publications/factbook/index.html>

described in table XIV is reflected here in terms of rank. Korea started in 34th position and gradually improved its ranking to finish in 24th position, for an overall average rank of 27.

Table XVI Ranking of leading and developing countries according to their per capita number of papers in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Switzerland	1	1	1	1	1
Sweden	2	2	2	2	2
Netherlands	3	4	4	5	4
United Kingdom	6	6	7	9	8
Canada	9	8	8	11	9
United States	7	9	12	12	10
Australia	11	11	10	10	11
France	13	14	14	15	14
Germany	15	16	15	14	15
Japan	16	17	17	17	17
Italy	18	19	19	22	19
Spain	21	21	20	23	21
Republic of Korea	34	32	26	24	27
Cuba	32	34	35	34	35
South Africa	33	39	40	39	38
Brazil	41	43	42	41	42
Egypt	46	54	53	53	53
India	51	55	55	56	55
China	55	56	56	54	56

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4.2.2 Specialization index

The specialization index provides an assessment of the intensity of a country's scientific output in a given domain (or field) relative to its overall scientific output. In terms of specialization in health biotechnology, Switzerland is the leader among the leading countries. The SI clearly shows that, in the past, Canada did not produce as much in health biotechnology as one might have expected, given its share of world scientific output in general. Over the 12-year period examined, Canada was last, save Spain, in terms of the SI (Table XVII). Each of the developing countries studied here improved their SI during the 12-year period. Only Cuba and the Republic of Korea were above the world average, with the remaining developing countries being greatly under specialized in health biotechnology. Cuba was the most specialized country in the world during the period studied, with an average SI of 2.63. In the case of the Republic of Korea, the SI grew steadily from 0.84 in 1991-1993 to 1.31 in 2000-2002, for an overall average of 1.20. This, again, clearly shows the amazing development of Korean science.

Table XVII Specialization index of leading and developing countries in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Cuba	2.35	2.83	2.56	2.71	2.63
Switzerland	1.60	1.46	1.37	1.35	1.43
Japan	1.44	1.43	1.39	1.34	1.40
Netherlands	1.49	1.37	1.38	1.30	1.38
Sweden	1.31	1.22	1.30	1.28	1.28
Republic of Korea	0.84	1.12	1.27	1.31	1.20
France	1.25	1.21	1.11	1.06	1.15
Germany	1.11	1.10	1.12	1.17	1.12
United States	1.10	1.13	1.12	1.10	1.12
United Kingdom	1.12	1.04	1.04	0.97	1.04
Italy	1.06	1.05	1.02	0.99	1.02
Australia	1.05	0.98	1.01	0.97	1.00
Canada	0.89	0.93	1.02	1.00	0.96
Spain	0.67	0.82	0.93	0.93	0.85
Brazil	0.59	0.72	0.73	0.95	0.78
South Africa	0.54	0.50	0.62	0.80	0.61
India	0.36	0.44	0.56	0.74	0.53
China	0.32	0.31	0.36	0.56	0.42
Egypt	0.29	0.30	0.40	0.41	0.35
World	1.00	1.00	1.00	1.00	1.00

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table XVIII translates the table XVII numbers in ranks. Cuba is the absolute leader of this ranking with a constant 1st position throughout the 12 years of this study. Switzerland, Sweden, and France started strong but lost some ranks during the 12-year period. Japan managed to slightly improve its position having started in 6th place and finished in 5th place for an overall average rank of 4. Canada managed to improve its ranking, starting from 20th position to finish in the 19th position for an overall average rank of 21 for the 12-year period. Korea greatly improved its ranking throughout the 12 years. It started in 21st place in 1991-1993, reaching an impressive 7th place in 2000-2002, for an overall average rank of 11. Among the developing countries, Brazil, India, and China also managed to improve their ranking (Brazil jumping from 33rd to 23rd position, India from 48th to 34th, and China from 50th to 48th). In contrast, South Africa fell from 34th position in 1991-1993 to 38th position in 1997-2000. Nevertheless, it regained some ground in 2000-2002, when it climbed to 31st, for an overall average of rank of 37.

Table XVIII Ranking of leading and developing countries according to their specialization index in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
Cuba	1	1	1	1	1
Switzerland	2	3	6	4	2
Japan	6	4	4	5	4
Netherlands	5	6	5	8	5
Sweden	9	11	8	10	10
Republic of Korea	21	14	11	7	11
France	10	12	15	15	12
Germany	13	15	13	11	13
United States	14	13	14	14	14
United Kingdom	12	18	17	21	16
Italy	17	17	18	20	17
Australia	18	20	21	22	19
Canada	20	22	19	19	21
Spain	29	26	23	24	24
Brazil	33	31	32	23	29
South Africa	34	39	38	31	37
India	48	46	45	34	45
China	50	54	54	48	51
Egypt	53	55	52	54	55

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4.2.3 Average relative impact factor

The average relative impact factor (ARIF) is used to evaluate the expected impact of papers from each country compared to other papers in health biotechnology at the world level. This indicator provides a proxy for the quality of the journals in which papers are published: the higher the index value, the higher the average quality of a journal is. For instance, the United States and Switzerland both have papers in health biotechnology whose expected impact is considerably higher than that of other countries (by 20% and 13% respectively) (Table XIX). They are followed by Canada and the Netherlands, which both published health biotechnology papers in journals that were cited 7% and 6% more than the world average for health biotechnology. Among developed countries, Japan, with a factor of 0.88, had the lowest ARIF for the 12-year period studied. In the case of developing countries, none had an ARIF above the world average of 1. South Africa was closest to the world benchmark, peaking in 1994-1996 with an ARIF of 0.91, averaging 0.81 for the 12-year period as a whole. Brazil (0.74), Korea (0.72), and Egypt (0.72) come in next, with Cuba (0.57), India (0.57), and China (0.54) not far behind.

Table XIX Average relative impact factor of leading and developing countries in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	1.21	1.20	1.19	1.20	1.20
Switzerland	1.07	1.14	1.17	1.12	1.13
Canada	1.03	1.05	1.08	1.13	1.07
Netherlands	1.00	1.04	1.08	1.10	1.06
United Kingdom	0.99	1.02	1.08	1.08	1.04
France	0.92	0.97	1.01	1.04	0.98
Australia	0.95	0.97	0.95	0.99	0.97
Sweden	0.89	0.93	0.98	1.02	0.96
Germany	0.89	0.92	0.98	1.00	0.95
Spain	0.88	0.91	0.97	0.96	0.94
Italy	0.84	0.93	0.92	0.96	0.92
Japan	0.88	0.87	0.89	0.90	0.88
South Africa	0.74	0.91	0.77	0.81	0.81
Brazil	0.66	0.72	0.73	0.77	0.74
Republic of Korea	0.91	0.85	0.66	0.71	0.72
Egypt	0.59	0.77	0.72	0.74	0.72
Cuba	0.54	0.58	0.53	0.62	0.57
India	0.56	0.54	0.58	0.58	0.57
China	0.60	0.53	0.48	0.57	0.54
World	1.00	1.00	1.00	1.00	1.00

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table XX represents table XIX in terms of ranks. The United States oscillated between 1st and 2nd place throughout the 12 year period studied, landing an average 1st place. Switzerland ranked second for the 12 years, starting in 5th place and finishing in third. Canada performed very well, starting in 7th place and finishing in 2nd, for an overall average rank of 4. Most of the other developed countries experienced a gain in rank between the 1991-1993 and 1994-1997 periods, eventually stabilizing their positions. In the case of developing countries, all gained in rank during the 12 years, except for Korea and China. Korea experienced a strong drop in rank, falling from the 18th to 40th position; a radically different performance from the other indicators presented in this report. China, for its part, dropped from 46th to 55th place, thus occupying the last position of the countries examined in this study. This apparent drop in quality of Chinese and Korean papers may be worth examining in the future. South Africa is the developing country that witnessed the most important gain in rank, passing from 40th to 29th position for an overall average rank of 33. Brazil is not far behind, starting in 43rd place and finishing in 36th, for an overall average rank of 39.

Table XX Ranking of leading and developing countries according to their average relative impact factor in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	2	1	2	1	1
Switzerland	5	2	3	3	2
Canada	7	4	7	2	4
Netherlands	11	6	6	5	5
United Kingdom	12	8	5	6	7
France	17	12	11	11	10
Australia	14	13	19	16	12
Sweden	25	16	15	13	13
Germany	26	18	13	15	14
Spain	28	22	17	18	15
Italy	30	17	21	17	18
Japan	27	23	23	24	21
South Africa	40	21	37	29	33
Brazil	43	39	41	36	39
Republic of Korea	18	27	45	40	42
Egypt	48	33	43	38	43
Cuba	55	51	54	47	52
India	54	53	50	53	53
China	46	54	57	55	55

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4.2.4 Average relative citation

As we previously mentioned, whereas the impact factor provides a measure of the average number of citations received by journals, and thus an expected citation score, the average relative citation is an indicator of the number of times papers published by a country are actually cited relative to the world average. Again, a score above one (1) denotes that a country's health biotechnology papers are cited more often than the average paper in health biotechnology.

Contrary to the situation in genomics, the United States managed to keep its 1st place for this indicator, having the greatest number of *observed citations* per paper on average (Table XXI). This is coherent with the United States' first-place position in terms of *expected citations* (Table XX). Nevertheless, we can safely assume that Switzerland will surpass the United States in the short term for this indicator, since it went from 1.14 to 1.37 between 1991-1993 and 2000-2002. For the 12-year period, the papers published by the Netherlands were also cited significantly more often than those of the other countries measured. Papers published by the United Kingdom, Canada, Sweden, and Germany were also, on average, cited more often than the world average. It is important to mention the Canadian performance for this indicator: beginning at the level of the world average in 1991-1993, Canada achieved an average relative citation of 1.25 by the end of the 12-year period studied, meaning that its papers in health biotechnology were cited 25% more than the average world paper was. Over the 12-year period, Canada ranked 9 in terms of ARC, right behind the United Kingdom

(situated at rank 10). Importantly though, Canada was the developed country that experienced the greatest gain of rank during this period (Table XXI), beginning in 10th position in 1991-1993 and finally reaching the 4th position in 2000-2002, surpassing the Netherlands and the United Kingdom.

Table XXI Average relative citations in health biotechnology of leading and developing countries, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	1.26	1.27	1.27	1.29	1.27
Switzerland	1.14	1.30	1.23	1.37	1.26
Netherlands	1.18	1.11	1.15	1.25	1.17
United Kingdom	1.05	1.12	1.15	1.14	1.11
Canada	1.00	1.01	1.14	1.25	1.10
Sweden	1.02	1.05	1.08	1.15	1.08
Germany	0.95	1.01	1.05	1.05	1.02
France	0.96	1.02	1.00	1.01	1.00
Australia	0.92	1.00	1.01	1.03	0.99
Italy	0.79	0.92	0.91	0.92	0.89
Spain	0.68	0.73	0.94	0.99	0.87
Japan	0.86	0.79	0.86	0.88	0.85
South Africa	0.72	0.95	0.67	0.78	0.78
Brazil	0.49	0.74	0.67	0.60	0.63
Republic of Korea	0.65	0.62	0.62	0.55	0.59
China	0.47	0.51	0.42	0.40	0.43
Cuba	0.26	0.51	0.41	0.51	0.45
India	0.33	0.36	0.43	0.53	0.43
Egypt	0.36	0.48	0.41	0.36	0.40
World	1.00	1.00	1.00	1.00	1.00

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

For the developing countries chosen for this study, as in the case of the ARIF, none had ARC higher than one. Here, too, South Africa, Brazil, and Korea occupied the first three places among the observed developing countries. Among these countries, South Africa experienced the highest peak for this indicator; reaching a surprising 0.95 during the 1994-1996 period, which translated into 19th position (Table XXII), above Italy, Spain, and Japan. This largely explains why South Africa was the clear leader for this indicator among the developing countries studied, just like it was for the ARIF. Brazil came in 2nd place, with an average relative citation of 0.63 for the 12-year period studied. The Republic of Korea's average relative citation, just as in the case of the ARIF, decreased during the period studied. This was also reflected in its rank, which dropped from 32nd place in 1991-1993 to 40th in 1997-1999 and finally ended up in 36th place in 2000-2002, for an overall 39th place for the 12-year period. Brazil performs well on this indicator, even surpassing Spain in 1994-1996. In contrast, China, Cuba, India, and Egypt behaved very poorly on this indicator. Indeed, their papers were cited more than 50% less often than the average world paper was. It is nonetheless worth mentioning that

China performed better with respect to the average relative citation (47th) than it did in terms of the ARIF (55th).

Table XXII Ranking of leading countries according to average relative citations in health biotechnology, 1991-2002

Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
United States	2	2	1	3	1
Switzerland	4	1	2	1	2
Netherlands	3	9	5	5	4
United Kingdom	6	6	6	10	8
Canada	10	15	7	4	9
Sweden	8	12	11	9	10
Germany	17	16	12	14	11
France	16	14	15	17	13
Australia	19	18	14	16	14
Italy	25	21	18	20	16
Spain	30	31	17	18	19
Japan	22	26	24	22	21
South Africa	26	19	35	25	27
Brazil	39	29	36	35	38
Republic of Korea	32	38	40	36	39
China	41	43	53	42	47
Cuba	53	45	55	39	49
India	50	53	53	37	50
Egypt	49	48	56	52	54

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4.2.5 Multicriteria analysis

Like section 3.2.6, this section provides a multicriteria assessment of the leading countries in health biotechnology. Again, the criteria considered in the multicriteria ranking were number of papers, number of papers per capita, specialization index, average relative impact factor, and average relative citations. During the 12-year period considered here, Switzerland was the uncontested champion (Table XXIII). The Netherlands were second, followed by the United States (3rd) and Belgium (4th). The United Kingdom was 5th, Denmark 6th, Sweden 7th, Canada 8th, and France 10th.

In the case of developing countries chosen for this study, the Republic of Korea was 1st, ranking 21st overall, Brazil (2nd) was 30th, quickly followed by South Africa (3rd) in 31st place and Cuba (4th) in 32nd place. India (5th) was farther behind in 38th place, and China (6th) in 40th place. Egypt (7th) occupies the 45th and last position.

Table XXIII Multicriteria ranking of leading and developing countries in health biotechnology, 1991-2002

Rank	Country	1991-1993	1994-1996	1997-1999	2000-2002	1991-2002
1	Switzerland	1	1	1	1	1
2	Netherlands	3	3	2	2	2
3	United States	2	2	3	2	3
4	Belgium	5	4	9	4	4
5	United Kingdom	4	4	4	9	5
6	Denmark	8	8	5	7	6
7	Sweden	7	7	6	7	7
8	Austria	10	6	8	6	8
8	Canada	6	9	6	4	8
10	France	10	10	12	12	10
11	Finland	12	11	9	11	11
12	Germany	15	12	11	10	12
13	Japan	14	14	13	13	13
14	Australia	13	13	14	15	14
15	Israel	9	15	15	14	15
16	Italy	17	16	16	16	16
17	Norway	16	17	18	18	17
18	Spain	20	18	17	17	18
19	Ireland	20	26	19	19	19
20	New Zealand	18	19	21	22	20
21	Republic of Korea	25	19	21	20	21
22	Portugal	23	25	20	21	22
23	Taiwan	19	27	27	24	23
24	Greece	29	23	23	28	24
24	Thailand	22	19	24	25	24
26	Kenya	25	19	24	33	26
26	Singapore	24	24	26	31	26
28	Hong Kong	28	32	27	23	28
29	Czech Republic		29	31	26	29
30	Brazil	33	31	33	27	30
31	South Africa	30	28	35	30	31
32	Cuba	31	30	34	29	32
33	Argentina	32	36	32	34	33
33	Hungary	27	34	30	32	33
35	Slovenia	37	36	29	36	35
36	Mexico	34	35	37	37	36
37	Poland	34	39	38	38	37
38	India	40	40	39	35	38
39	Slovakia		33	40	42	39
40	China	38	41	43	39	40
41	Russian Federation	38	38	41	40	41
42	Chile	41	45	36	43	42
43	Turkey	42	42	42	41	43
44	Bulgaria	36	43	44	45	44
45	Egypt	43	44	45	44	45

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

* The global scores for the Czech and the Slovak republics are based on the last nine years.

Canada made some progress during the period covered by the study: whereas it was in 6th place in 1991-1993, it moved to 9th in 1994-1996, back to 6th in 1997-1999, and finally climbed to the 4th position in 2000-2002, for an overall average rank of 8, the same as Austria. The positions of most countries studied remained relatively stable during the 12 years covered by this study, although some

countries managed to increase their rank. Austria, for example, gained four positions over the four periods, reaching the 6th place in 2000-2002, with an overall average rank of 8. The performances of the developed countries chosen for this study were less volatile in the health biotechnology multicriteria ranking than in the genomics ranking. Most of the developing countries' ranks remained relatively stable during the 12-year time span.

As in the genomics multicriteria ranking, the internal construction of this ranking can be favourable to small countries, because it is easier for countries with low number of papers to maintain an overall strong impact factor and index of citations. This can help explain why the 12 leading countries in terms of publications do not necessarily occupy the 12 leading positions in this ranking, and why countries like Belgium, Denmark, and Austria have managed to assume leading positions.

4.2.6 International and national collaboration in and by developing countries

This section aims to provide a quantitative overview of international and national scientific collaboration trends in health biotechnology in and by the developing countries selected for this study. Each country's proportion of health biotechnology papers co-authored with international and national partners is shown in Figure 8.

Proportionally, developing countries generally published more papers in health biotechnology with international collaborators than with national collaborators (more than 30% of the health biotechnology papers published). The same collaboration dynamic can also be observed for genomics papers. But, again, two developing countries do not follow this trend toward international collaboration: the Republic of Korea and India. From 1995 to 2002, the Republic of Korea published more with national collaborators than it did with international partners (e.g.: in 2002: national collaboration accounted for 51.8% of papers and international collaboration for 24.1%). The same collaboration dynamic can be observed in Brazil, China, and Cuba in the years that followed: 1999-2002 data suggest that, proportionally, there was a trend for more national collaboration. As is the case for genomics, national collaboration in genome science in Brazil and China is therefore likely to be of more importance. Cuba's annual number of publications in health biotechnology is too small and fluctuates too much to confirm any trend toward scientific collaboration.

Similar to genomics publications, India had the lowest international and national collaboration rates in health biotechnology publications (international collaboration, 20.5% and national collaboration, 24.4%). This indicates that Indian researchers have, in comparison with other developing countries, tended to carry out research individually rather than in collaboration in both domains examined in this study. Egypt has a fairly high international collaboration rate (68.8% in 2002), but also the lowest national collaboration rate (12.5% in 2002), which demonstrates Egypt's scientific dependence on international activity in health biotechnology and, as we have previously seen, in genomics. South Africa also had a high rate of international collaboration: in 2002, 60% of South Africa's papers were published with international partners and 40% with South-African colleagues.

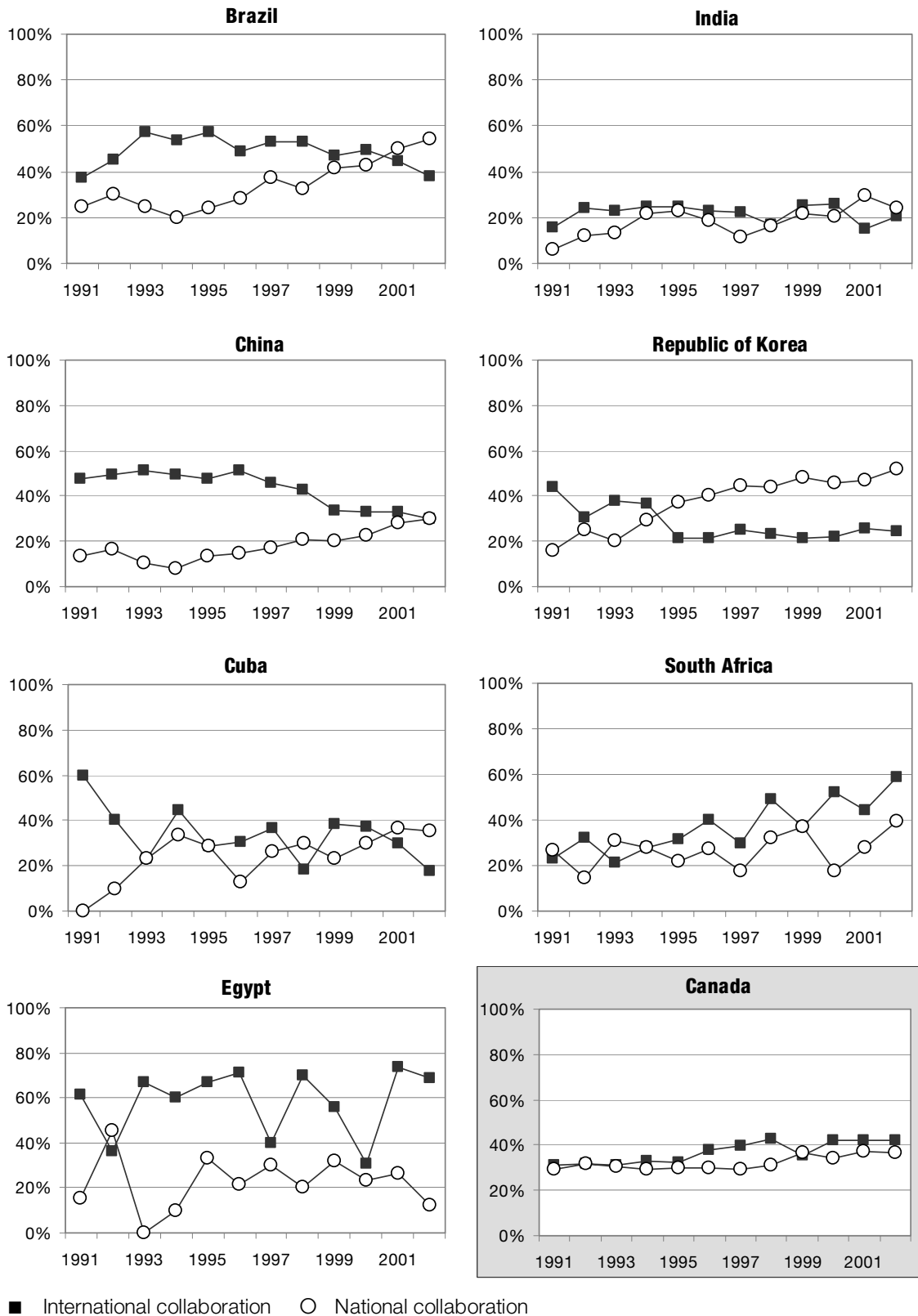


Figure 8 International and national collaboration rates of developing countries and Canada in health biotechnology, 1991-2002

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

4.2.7 Main countries that collaborate with developing countries in health biotechnology

As in genomics, the seven developing countries studied principally collaborated with the leading countries in health biotechnology: United States (46.4%), Japan (11.9%), United Kingdom (11.5%), Germany (8.3%), France (7.3%), and Canada (4.3%) (Table XII). The Republic of Korea collaborated most with the United States in terms of the number and proportion of co-authored papers. Japan was the second source of collaborators for both South Korean and Chinese researchers. The United Kingdom was the second source of collaborators for Brazil and India. Finally, Brazilian, Cuban, and South African researchers collaborated most with French partners. As in the case in genomics, this distribution is about the same as the share of the publications of leading countries in health biotechnology.

The number of papers published in health biotechnology with international collaborators other than those from the leading countries was often small (less than 10 papers annually). Consequently, it is difficult to infer any trends at the country level. In fact, the collaboration portfolio of one group of researchers or department may account for a country's international collaboration pattern as a whole. However, it is interesting to look at developing countries' most important institutional collaborators. Here are the main international institutional collaborators of each of the developing countries studied:

Brazil: Centers for Disease Control and Prevention (United States), Institut Pasteur (France), and Harvard University (United States)

China: University of Hong Kong (Hong Kong), Chinese University of Hong Kong (Hong Kong), National Cancer Institute (United States), and Hong Kong University of Science & Technology (Hong Kong)

Cuba: Consejo Superior de Investigaciones Cientificas (Spain) and Lunds Universitet (Sweden)

Egypt: University of Texas (United States) and Washington University (United States)

India: University of Ulster (United Kingdom), Harvard University (United States), and University of Texas (United States)

Republic of Korea: National Cancer Institute (United States), University of Texas (United States), and University of Tokyo (Japan)

South Africa: Katholieke Universitet Leuven (Belgium) and Lunds Universitet (Sweden)

Table XXIV Main countries that collaborate with developing countries in health biotechnology, 1991-2002

Country	Brazil	China	Cuba	Egypt	India	Republic of Korea	South Africa
United States	46.0%	36.6%	10.3%	60.6%	43.3%	64.9%	43.2%
United Kingdom	15.3%	8.8%	7.4%	6.4%	18.8%	3.6%	25.4%
Japan	4.4%	17.5%	0.0%	6.4%	8.3%	20.7%	2.2%
Germany	6.5%	9.1%	13.2%	9.6%	12.6%	4.2%	11.4%
France	11.6%	7.5%	10.3%	5.3%	5.6%	2.0%	10.8%
Canada	4.0%	4.4%	1.5%	1.1%	4.3%	5.4%	4.3%
Australia	3.3%	5.5%	0.0%	0.0%	2.2%	2.8%	4.9%
Italy	4.7%	2.9%	8.8%	4.3%	0.8%	1.0%	5.4%
Sweden	1.8%	3.2%	20.6%	0.0%	2.7%	1.2%	4.9%
Netherlands	4.2%	1.5%	2.9%	6.4%	2.4%	1.4%	6.5%
Hong Kong	0.0%	9.6%	0.0%	0.0%	0.3%	0.4%	0.0%
Belgium	4.2%	1.0%	0.0%	1.1%	1.6%	0.2%	7.6%
Denmark	1.4%	1.0%	4.4%	1.1%	2.2%	0.6%	3.2%
Spain	2.1%	0.5%	19.1%	1.1%	0.3%	0.2%	1.6%
Switzerland	1.8%	0.6%	0.0%	1.1%	3.0%	0.2%	3.8%
Israel	0.2%	1.3%	1.5%	6.4%	1.3%	0.8%	0.5%
Argentina	3.0%	0.2%	2.9%	0.0%	0.5%	0.0%	0.0%
Total collaboration (n)	569	617	68	94	372	498	185

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5 Genomics and health biotechnology at the national level in seven developing countries

Whereas the two previous sections examined how developing countries compared to the rest of the world in genomics and health biotechnology, this section examines the distribution of scientific output in the seven countries themselves. Section 5.1 presents data desegregated by field and subfield, section 5.2 looks at the distribution of papers by sectors of activity, and section 5.3 examines the distribution of papers by most active city and organization.

5.1 Scientific output by field and subfield

This section examines the distribution of genomic and health biotechnology papers according to a journal-based classification for each country. A country's degree of specialization is also presented in order to highlight in which fields developing countries put more or less effort than the world average in genomics and health biotechnology scientific papers. Table XXV shows statistics for the whole period (1991-2002) by domain/field for both genomics and health biotechnology. Because of the fairly high number of subfields for each field, data at the subfield level will be presented in the text only, and, solely, if it is of interest to the characterization of a country's scientific output.

Genomics

The most prolific fields in genomics are Biomedical Research and Clinical Medicine. As a proportion of the total output in genomics, only China and Egypt have not published as much, proportionally, as the average world effort in Biomedical Research. Inversely, only China and Egypt had an SI in Clinical Medicine that was near to or just above the world average (0.94 and 1.07); therefore, the clinical portion of genomic research in developing countries is underrepresented in comparison to what is observed at the world level. However, each developing country has specialization in at least one subfield in Biomedical Research and in Clinical Medicine.

In Biomedical Research, Brazil is highly specialized in Parasitology (SI of 7.13, 215 papers); although it is less specialized in Genetics and Heredity (1.48), this subfield is still quite important because of the country's high number of papers (859) in the field. India is highly specialized in Miscellaneous Biomedical Research (SI of 3.45, 104 papers) and Biomedical Engineering (SI of 2.45, 99 papers). The Republic of Korea is also highly specialized in Biomedical Engineering (SI of 7.35, 300 papers). Even though it does not produce a large number of papers, Cuban biomedical research particularly focuses on Biomedical Engineering and is 18 times more specialized than the world in this subfield. Thus, Biomedical Engineering is quite important in Biomedical Research with three countries highly specialized in this subfield. China is specialized in General Biomedicine (2.3) and also has a significant number of papers (814) in this subfield, which is also of importance to India (551 papers, SI of 1.81). South Africa is specialized in Virology (1.96) and Microbiology (1.89), where it produced 177 and 118 papers respectively.

In Clinical Medicine, Brazilian genome science focuses on Tropical Medicine (74 papers, SI of 11.4) and General and Internal Medicine (178 papers, SI of 2.11). China is also specialized in General and Internal Medicine (590 papers, SI of 4.5). India (400 papers, SI of 8.9) and South Africa (33 papers, SI of 2.37) focus on Veterinary Medicine, and the Republic of Korea on Otorhinolaryngology (40 papers, SI of 3.22). Despite the small number of papers Egypt has in Pharmacy (12) and Tropical Medicine (16), the country has an amazing level of specialization in both subfields (25.59 and 19.49 respectively).

In genomics, Biology is the only field in which all developing countries are more specialized than the world average. India, South Africa, Brazil, Egypt, and China all had a high SI in Biology and also published a relatively high number of papers in this field. In contrast, many of the leading developed countries are not specialized in the field of Biology. These include the United States (0.79), the United Kingdom (0.88), the Netherlands (0.93), Sweden (0.74), Switzerland (0.68), France (0.84), Germany (0.92), and Italy (0.73). In terms of Biology subfields, India is highly specialized in Agriculture & Food Science (SI of 5.65, 335 papers) and Botany (SI of 2.26, 479 papers); Brazil in Miscellaneous Zoology (SI of 3.69, 23 papers), Miscellaneous Biology (SI of 2.81, 25 papers), Entomology (SI of 2.63, 59 papers), and Botany (SI of 1.89, 296 papers); South Africa in Miscellaneous Zoology (SI of 8.05, 21 papers), General Zoology (SI of 3.93, 24 papers), Entomology (SI of 3.26, 27 papers), and Botany (SI of 2.64, 173 papers); Egypt in Dairy & Animal Science (SI of 6.4, 21 papers), Entomology (SI of 4.81, 12 papers), and Agriculture & Food Science (SI of 2.89, 16 papers); and finally, China in General Biology (SI of 14.08, 289 papers).

China dominates Chemistry with 665 papers and is over 420% more specialized than the world in this field of genomics (1991-2002). Chinese genomics related to Chemistry specialized in three subfields: Analytical Chemistry (5.9), General Chemistry (5.9), and Inorganic & Nuclear Chemistry (6.9). During the same period, India was also prolific in Chemistry, both in terms of number of papers (309) and in terms of SI (2.2). India is also highly specialized in Inorganic & Nuclear Chemistry (7.3) and, to a lesser extent, in Physical Chemistry (4.0). The Republic of Korea is the third-largest producer in Chemistry (172 papers) among developing countries. South Korea has principally specialized in Polymers (3.4).

Health biotechnology

The bibliographic domain of health biotechnology is divided in only two fields: Biomedical Research and Clinical Medicine. Therefore, countries are automatically specialized in one of the two fields, or they are neutral in terms of specialization (both have SI equal to 1.00).

Within health biotechnology, the most specialized countries in Biomedical Research are India and the Republic of Korea, each with over 30% more papers in this field, proportionately, than the world average. Both countries had a high degree of specialization in Biomedical Engineering (over 300% more specialized than the world in this subfield of health biotechnology). As was the case in genomics, Cuba is also specialized in health-biotechnology-related Biomedical Engineering (46 papers, SI of 3.75). It is also noteworthy that all the seven developing countries keep up with the world's degree of specialization in health-biotechnology-related Biomedical Research, but this is not

the case in Clinical Medicine. In fact, India and the Republic of Korea's specialization indices were respectively 42% and 45% below the world's average specialization in Clinical Medicine research. The same is true, albeit to a lesser extent, for Brazil and China. Therefore, we can assume that health biotechnology R&D is not clinically oriented in the developing countries studied here, especially when we look at the data for developed countries. Most leading developed countries in health biotechnology are more, even if only slightly more, specialized in Clinical Medicine than they are in Biomedical Research when compared to the world as a whole: Australia (1.04 vs. 0.97), Germany (1.03 vs. 0.98), Italy (1.24 vs. 0.82), Japan (1.08 vs. 0.94), Netherlands (1.13 vs. 0.91), Sweden (1.09 vs. 0.94), Switzerland (1.05 vs. 0.96), and United States (1.03 vs. 0.98). Considering that the number of papers published by the leading developed countries is much higher than that of developing countries, this specialization is a significant one. Of the developed countries, only Canada and Spain (Canada SI: 0.89; Spain SI: 0.85) are not as specialized in Clinical Medicine as the world is. In health biotechnology, specialization of developing countries in subfields within Biomedical Research and Clinical Medicine are similar to those observed in genomics with the exception of Otorhinolaryngology in the case of the Republic of Korea and of Pharmacy in the case of Egypt.

Table XXV Developing countries in genomics and in health biotechnology, 1991-2002: number of papers and specialization index¹ by field

Domain/Field	Brazil		China		Cuba		Egypt		India		Rep. of Korea		South Africa	
	Papers	S.I	Papers	S.I	Papers	S.I	Papers	S.I	Papers	S.I	Papers	S.I	Papers	S.I
Genomics														
Biology	565	1.74	872	1.73	26	1.13	95	2.32	950	2.16	508	1.14	325	2.39
Biomedical Research	2,517	1.02	3,002	0.78	185	1.06	194	0.62	3,392	1.01	3,539	1.05	1,034	1.00
Chemistry	54	0.53	665	4.20	21	2.92	65	5.06	309	2.24	172	1.24	14	0.33
Clinical Medicine	1,363	0.84	2,358	0.94	87	0.76	217	1.07	1,385	0.63	1,937	0.88	509	0.75
Earth & Space	8	n.s.	42	2.93			1	n.s.	21	1.68	14	1.11	17	4.41
Engineering & Tech.	8	n.s.	21	2.16			1	n.s.	33	3.91	21	2.46	1	n.s.
Mathematics	2	n.s.	4	n.s.					4	n.s.				
Physics	30	2.62	99	5.56	2	n.s.			51	3.29	16	1.02	2	n.s.
Health Biotechnology														
Biomedical Research	771	1.13	999	1.07	124	1.00	92	1.00	1,301	1.31	1,576	1.34	311	1.14
Clinical Medicine	415	0.83	622	0.91	92	1.01	67	1.00	421	0.58	470	0.54	164	0.82

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

¹ Based on domain totals.

5.2 Scientific output by institutional sector of activity

This section presents the distribution of scientific papers in the seven developing countries studied by institutional sector of activity. This sector-based distribution gives a broad overview of the national dynamics of scientific output in genomics and health biotechnology.

In the case of each developing country, Table XXVI shows roughly the same patterns of sector-based scientific contribution for both genomics and health biotechnology. In some countries, however, governmental institutions are proportionally more active in health biotechnology than they are in

genomics. In fact, there are over 7% more government-authored publications in health biotechnology than they are in genomics in Brazil, Cuba, Egypt and, to in a lesser extent, the Republic of Korea (5%) and India (2.6%). In China and South Africa, governmental institutions proportionally produced about the same number of papers in both genomics and health biotechnology.

With the exception of Cuba scientists from universities in developing countries authored the majority of the papers in genomics and health biotechnology, so that universities dominate both domains. In fact, the university sector dominates the domain of genomics and health biotechnology in the developing countries studied, accounting for 80% in Brazil, Egypt, and South Africa, and for more than 90% in the Republic of Korea.

Cuba stands out for the number of papers published by governmental institutions: 88% of genomics papers and 97.2% of health biotechnology papers were produced by governmental institutions. Cuban universities have approximately the same importance as hospitals in terms of their contribution to genomics and health biotechnology (around 10%).

As in Cuba, albeit to a lesser extent, the government also plays an important role in Chinese and Indian R&D in both domains. In fact, Chinese and Indian governmental institutions are responsible for more than 35% of their respective national scientific output in genomics and health biotechnology. Proportionally, among the universities of the developing countries central to this study, Indian and Cuban universities produced the lowest number of papers.

Moreover, in both domains, governmental institutions are proportionately more active than clinics and hospitals in the developing countries studied. This could indicate that healthcare institutions in developing countries are not as R&D-oriented as governmental institutions. Nonetheless, the healthcare sector was accountable for 7% to 8% of the papers published by South Africa, China, and India in genomics and health biotechnology.

South Korean companies are exceptionally prolific and well positioned in genomics and health biotechnology in comparison to the other developing countries studied. Over the whole period, they produced 4.4% of national publications in genomics and 7% of national publications in health biotechnology. Generally, companies are the least important institutional sector of activity in the publication portfolio of all the developing countries studied. However, the same is true for most developed countries.

Table XXVI Number of papers and distribution of scientific output in genomics and in health biotechnology in developing countries by sector of activity, 1991-2002

Domain/Sector	Brazil		China		Cuba		Egypt		India		Rep. of Korea		South Africa	
	Papers	%	Papers	%	Papers	%	Papers	%	Papers	%	Papers	%	Papers	%
Genomics														
University	3,833	84.3%	4,670	66.1%	33	10.3%	475	82.9%	3,190	51.9%	5,700	91.8%	1,663	87.4%
Government	1,074	23.6%	2,630	37.2%	288	89.7%	120	20.9%	2,497	40.6%	934	15.0%	461	24.2%
Clinics & Hospitals	242	5.3%	538	7.6%	31	9.7%	16	2.8%	441	7.2%	411	6.6%	161	8.5%
Company	50	1.1%	51	0.7%	0.0%	0.0%	3	0.5%	59	1.0%	275	4.4%	32	1.7%
Other	206	4.5%	16	0.2%	2	0.6%	15	2.6%	704	11.5%	91	1.5%	55	2.9%
Unknown	167	3.7%	251	3.6%	12	3.7%	9	1.6%	200	3.3%	167	2.7%	6	0.3%
TOTAL (N)	4,547	100%	7,063	100%	321	100%	573	100%	6,145	100%	6,207	100%	1,902	100%
Health Biotechnology														
University	974	82.1%	1,073	66.2%	22	10.2%	125	78.6%	872	50.6%	1,830	89.4%	408	85.9%
Government	369	31.1%	592	36.5%	210	97.2%	44	27.7%	745	43.3%	411	20.1%	107	22.5%
Clinics & Hospitals	46	3.9%	121	7.5%	15	6.9%	4	2.5%	141	8.2%	98	4.8%	39	8.2%
Company	25	2.1%	26	1.6%	1	0.5%	3	1.9%	29	1.7%	147	7.2%	14	2.9%
Other	75	6.3%	1	0.1%	0.0%	0.0%	13	8.2%	148	8.6%	34	1.7%	6	1.3%
Unknown	46	3.9%	65	4.0%	4	1.9%	3	1.9%	50	2.9%	59	2.9%	3	0.6%
TOTAL (N)	1,186	100%	1,621	100%	216	100%	159	100%	1,722	100%	2,046	100%	475	100%

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5.3 Scientific output by city and institution

5.3.1 Brazil

Table XXVII shows that, in terms of the number of publications, Sao Paulo was the most active city, in Brazil, with 1,637 papers in genomics and 428 in health biotechnology. Sao Paulo's scientific papers were, on average, published in journals with smaller impact factors than the world average, but it still ranks well within Brazil in terms of impact factor. Indeed, in terms of ARIF, Sao Paulo ranked 3rd in genomics and 5th in health biotechnology. In terms of the average relative citation, the picture is similar in genomics, where Sao Paulo ranks 5th, but not in health biotechnology, where Sao Paulo has an ARC lower than the country average for the most active cities. It is worth noting that, although Salvador is among Brazil's least productive cities in terms of number of papers, in terms of ARIF, it ranks 1st in both genomics (0.89) and health biotechnology, where its papers had on average 18% more impact than the world average.

In terms of ARC, Salvador ranks 1st in genomics (1.06) and 2nd in health biotechnology (1.02), its papers being cited as often as the world average in both domains. Other performing cities include Rio Janeiro, Belo Horizonte, Curitiba, and Belem. Rio Janeiro and Belo Horizonte published more papers than the country average in both genomics and health biotechnology. Moreover, in genomics and health biotechnology respectively, Belo Horizonte ranked 4th and 3rd in terms of ARIF and 3rd and 4th in terms of ARC. Although Curitiba published less than the country's average, it ranked 2nd in genomics in terms of ARIF. In terms of ARC, it ranked 4th in genomics and 1st in health

biotechnology (1.08), with its papers being cited as often as the world average. Similarly to Curitiba, Belem published less than the country's average, but performed well in genomics in terms of ARC, where it ranks 2nd, and in health biotechnology in terms of ARIF, where it also ranks 2nd.

Table XXVII Most active Brazilian cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
Sao Paulo	1,637	0.81	0.67	428	0.76	0.56
Rio Janeiro	876	0.74	0.61	272	0.76	0.67
Belo Horizonte	381	0.77	0.72	159	0.80	0.77
Campinas	338	0.69	0.50	81	0.60	0.42
Porto Alegre	321	0.70	0.51	56	0.77	0.51
Ribeirao Preto	311	0.61	0.56	53	0.76	0.87
Brasilia	214	0.63	0.34	52	0.62	0.44
Curitiba	113	0.84	0.68	44	0.69	1.08
Belem	103	0.76	0.85	15	0.84	0.62
Recife	95	0.56	0.42	34	0.55	0.29
Botucatu	95	0.68	0.46	8	n.s.	0.37
Sao Carlos	85	0.55	0.64	27	0.56	0.62
Piracicaba	80	0.66	0.65	11	0.49	0.24
Londrina	71	0.63	0.66	17	0.58	0.64
Salvador	65	0.89	1.06	27	1.18	1.02
Vicosa	64	0.46	0.23	11	0.60	0.37

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table XXVIII shows that the the university and governmental sectors are the main institutions that contribute to Brazilian publications in genomics and health biotechnology. Overall, seven universities and two governmental institutions published more papers than the country's average for the most active institutions. Among them, the Universidade de São Paulo and the Universidade Federal do Rio de Janeiro occupy the 1st and 2nd ranks in genomics with 1,441 and 493 publications respectively. A governmental institution, the Fundação Oswaldo Cruz, ranks 3rd, with 471 publications.

Table XXVIII Most active Brazilian institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
Universidade de São Paulo	1,441	0.80	0.67	306	0.74	0.55
Universidade Federal do Rio de Janeiro	493	0.75	0.53	135	0.69	0.52
Universidade Estadual de Campinas	337	0.68	0.52	81	0.58	0.44
Universidade Federal de Minas Gerais	321	0.78	0.68	134	0.82	0.72
Universidade Federal de São Paulo	301	0.79	0.60	95	0.82	0.77
Universidade Federal do Rio Grande do Sul	283	0.63	0.48	48	0.77	0.55
Universidade Estadual Paulista	222	0.67	0.44	34	0.62	0.39
Universidade Federal do Paraná	97	0.74	0.67	39	0.67	1.14
Universidade de Brasília	97	0.62	0.34	31	0.65	0.40
Universidade do Estado do Rio de Janeiro	83	0.72	0.74	23	0.78	0.70
Universidade Federal de Pernambuco	62	0.48	0.28	24	0.54	0.21
Universidade Federal de Viçosa	65	0.45	0.23	12	0.66	0.34
Universidade Federal de São Carlos	61	0.36	0.27	16	0.46	0.28
Universidade Federal do Pará	65	0.73	0.75	6	n.s.	0.62
Universidade Federal de Santa Catarina	51	0.79	0.60	10	0.54	0.28
Universidade Federal Fluminense	44	0.57	0.45	7	n.s.	0.86
Government						
Fundação Oswaldo Cruz	471	0.68	0.67	195	0.76	0.78
Brazilian Agricultural Research Corp. (Embrapa)	214	0.62	0.36	41	0.62	0.46
Instituto Butantan	82	0.70	0.45	49	0.75	0.41
Instituto Adolfo Lutz	44	0.80	0.52	25	0.81	0.59
Instituto Nacional de Câncer	40	0.69	0.48	7	n.s.	0.89
Instituto Nacional de Pesquisas Espaciais	29	0.55	0.67	3	n.s.	0.30
Instituto Evandro Chagas	24	0.91	1.31	8	n.s.	0.71
Fundação Ezequiel Dias	18	0.57	0.37	8	n.s.	0.39
Instituto Agrônomo	17	0.42	0.41	1	n.s.	0.36
Comissão Nacional de Energia Nuclear	10	0.64	0.40	5	n.s.	0.09
Instituto Agrônomo do Paraná	11	0.77	1.19	3	n.s.	0.87
Clinics & Hospitals						
Hospital do Câncer - AC Camargo	35	0.76	0.54	11	0.87	0.24
Hospital de Clínicas de Porto Alegre	26	0.95	0.73	1	n.s.	0.99
Hospital das Clínicas de São Paulo	15	0.82	0.76			
Hospital Sírio-Libanês	7	n.s.	0.50	4	n.s.	0.07
Instituto Materno Infantil de Pernambuco	7	n.s.	0.74	1	n.s.	0.00
Company						
Centro de Tecnologia Copersucar	8	n.s.	0.65	2	n.s.	0.15
Núcleo de Genética Médica de Minas Gerais	6	n.s.	1.35	3	n.s.	0.85
Other						
Ludwig Institute for Cancer Research	118	0.86	0.72	40	0.76	0.75
Fundação Pró-Sangue	35	0.55	0.35	14	0.72	0.43

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

With 306 publications, the Universidade de São Paulo is also 1st in health biotechnology, while the Universidade Federal do Rio de Janeiro is in 3rd place with 135 publications and the Fundação Oswaldo Cruz in 2nd place with 195. No Brazilian institution published papers that had an impact factor greater than the world's average, whether in genomics or health biotechnology. In genomics, the Hospital de Clínicas de Porto Alegre ranks 1st with an ARIF of 0.95, followed by the Instituto Nacional de Pesquisas Espaciais with an ARIF of 0.91. In health biotechnology, the Hospital do Câncer – AC Camargo ranks 1st with an ARIF of 0.87, followed by the Universidade Federal de Minas Gerais and the Universidade Federal de São Paulo, which both have an ARIF of 0.82 and published more than the country's average of the most active institutions. Papers from one company and two governmental institutions received, on average, more citations than the world average. These are the Nucleo de Genetica Medica de Minas Gerais with an ARC of 1.35, the Instituto Evandro Chagas with an ARC of 1.31 and the Instituto Agrônomo do Paraná with an ARC of 1.19. In health biotechnology, the Universidade Federal do Paraná (ARC of 1.14) is the only institution to have received, on average, more citations for its papers than the world average. Clinics and hospitals made a small contribution to Brazilian publications. An interesting research group is that of Andrew J. G. Simpson, based at the Ludwig Institute for Cancer Research, which published 79 papers in genomics and 38 papers in health biotechnology, representing three-quarters of the parent institute's output. The institute ranks 10th in both domains in terms of number of papers and has an ARIF and an ARC greater than the country average in both genomics and health biotechnology. Other prolific researchers include Sérgio D.J. Pena from the Universidade Federal de Minas Gerais, Mayana Zatz, Maria Rita Passos-Bueno, and Marco Antonio Zago, all three from the University of São Paulo.

5.3.2 China

In China, Beijing is the most active city in both domains, having published 2,472 papers in genomics and 623 in health biotechnology (Table XXIX). Other leading cities that published more papers than the country average for most active cities include Shanghai, with 1,613 papers in genomics and 406 papers in health biotechnology, and Wuhan, with 466 papers in genomics. In terms of ARIF and ARC, there was not much variation among cities. On average, papers from Chinese cities had an impact factor of about 50% of the world impact factor, and they were cited, on average, about 50% less than the world's papers as a whole. Although Hebei and Shenyang are among China's least productive cities in terms of papers in genomics and health biotechnology, they perform fairly well when considering their ARIFs and the ARCs. In terms of ARIF, Hebei ranks 1st in genomics (0.80) and health biotechnology, where its papers had on average 24% more impact than the world average. In terms of ARC, Hebei ranks 2nd in genomics (0.69) and 2nd in health biotechnology (0.74). In terms of ARIF, Shenyang ranks 2nd in genomics (0.61) and health biotechnology (0.87). In terms of ARC, Shenyang ranks 4th in genomics (0.63) and 1st in health biotechnology (0.87).

Table XXIX Most active Chinese cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
Beijing	2,472	0.50	0.48	623	0.50	0.35
Shanghai	1,613	0.61	0.61	406	0.63	0.51
Wuhan	466	0.48	0.45	101	0.49	0.64
Nanjing	367	0.49	0.36	79	0.40	0.36
Guangzhou	350	0.55	0.53	72	0.40	0.11
Hangzhou	300	0.52	0.57	57	0.54	0.39
Changsha	223	0.58	0.85	27	0.41	0.46
Tianjin	155	0.50	0.45	48	0.55	0.61
Chengdu	169	0.59	0.66	26	0.41	0.28
Xian	157	0.52	0.55	35	0.42	0.19
Kunming	162	0.61	0.43	16	0.76	0.19
Changchun	138	0.51	0.34	26	0.68	0.49
Shenyang	107	0.61	0.63	12	0.87	0.87
Hebei	94	0.80	0.69	11	1.24	0.74
Chongqing	86	0.42	0.24	14	0.54	0.22

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

In China, the main institutions that contribute to genomics and health biotechnology publications come from the university sectors (Table XXX). Overall, seven universities published more papers than the country average for most active institutions in genomics (155 papers), and eight universities (37 papers) did so in health biotechnology. Among these universities, the Fudan University ranks 1st in genomics and in health biotechnology with 590 and 170 papers respectively. The Shanghai Second Medical University is the only university that performed better in genomics than the country average for most active institutions in terms of ARIF and ARC. In health biotechnology, both the Shanghai Second Medical University and the Chinese Academy of Preventive Medicine performed better than the country average for most active institutions in terms of ARIF and ARC.

The Chinese Academy of Sciences is the most active Chinese institution in both domains. The Chinese Academy of Medical Sciences ranks 3rd in terms of total output behind the Fudan University. Although no other governmental institutions, outside of governmental Chinese academies produced more papers than the country average for most active institutions in genomics and health biotechnology. However, two governmental institutions performed incredibly well in genomics when considering the ARIF and ARC: the Chinese National Human Genome Center and the Qidong Liver Cancer Institute. The papers published by the Chinese National Human Genome Center and the Qidong Liver Cancer Institute had, on average, 41% and 17% more impact than the world average, ranking these institutions 1st and 2nd. Furthermore, papers from these two institutes received, on average, more than twice the number of citations than the world's papers did. With an ARC of 2.73, the Chinese National Human Genome Center ranks 1st, followed by the Qidong Liver Cancer Institute with an ARC of 2.10. Clinics and hospitals did not make a significant contribution to Chinese publications.

Table XXX Most active Chinese institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
Fudan University	590	0.58	0.54	170	0.54	0.47
Peking University	327	0.56	0.60	92	0.47	0.21
Beijing Medical University	241	0.47	0.45	48	0.33	0.22
Zhongshan University	238	0.57	0.67	43	0.37	0.07
Wuhan University	178	0.38	0.24	34	0.38	0.29
Shanghai Second Medical University	171	0.80	0.95	37	0.97	0.79
Zhejiang University	158	0.54	0.65	30	0.68	0.42
Nanjing University	149	0.40	0.25	36	0.33	0.19
Tsinghua University	123	0.54	0.61	48	0.50	0.52
Second Military Medical University	142	0.60	0.41	34	0.68	0.43
Sichuan University	133	0.59	0.62	20	0.37	0.21
Hunan Medical University	126	0.55	0.55	16	0.20	0.08
Fourth Military Medical University	108	0.56	0.38	25	0.36	0.24
Huazhong University of Science & Technology	97	0.53	0.68	36	0.57	1.13
China Agricultural University	102	0.43	0.40	18	0.29	0.12
Huazhong Agricultural University	104	0.55	0.47	20	0.69	0.54
Government						
Chinese Academy of Sciences	1,703	0.53	0.49	318	0.51	0.31
Chinese Academy of Medical Sciences	359	0.55	0.53	108	0.52	0.46
Chinese Academy of Preventive Medicine	135	0.72	0.71	50	0.88	0.94
Chinese Academy of Agricultural Sciences	138	0.36	0.33	33	0.42	0.24
Academy of Military Medical Science	99	0.29	0.18	39	0.37	0.19
Chinese National Human Genome Center	50	1.41	2.73	7	n.s.	0.79
Zhejiang Academy of Agricultural Sciences	36	0.47	0.43	3	n.s.	0.86
China National Rice Research Institute	23	0.30	0.22	1	n.s.	0.00
Ministry of Public Health	15	0.49	0.25	3	n.s.	0.33
Natl Inst. for the Control of Pharma. & Biol. Prod.	12	0.66	0.79	5	n.s.	0.46
Qidong Liver Cancer Institute	12	1.17	2.10	1	n.s.	2.93
National Research Institute for Family Planning	12	0.23	0.24	4	n.s.	0.60
Clinics & Hospitals						
Peking Union Medical College Hospital	34	0.42	0.39	6	0.46	0.47
Chinese Peoples Liberation Army Gen. Hospital	30	0.44	0.28	6	n.s.	0.44
Shanghai Children's Hospital	32	0.66	0.23	3	n.s.	0.10
China-Japan Friendship Hospital	12	0.79	0.96	4	n.s.	0.99
Shanghai Hospital	13	0.55	0.28	5	n.s.	1.09
Shanghai Mental Health Hospital	12	0.69	0.40			
Beijing Hospital	8	n.s.	0.43	6	n.s.	0.89
Company						
United Gene Holdings Ltd	16	0.37	0.29	13	0.47	0.48
Other						
China Center of Advanced S&T	5	n.s.	0.72	0		0.78

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5.3.3 Cuba

In Cuba, most of the scientific activity in genomics and health biotechnology is concentrated in Havana, which holds 90% of the papers in genomics and 95% of the papers in health biotechnology. In most cases, the ARIF and ARC did not have great relevance, due to the small number of papers published per city. Therefore, these indicators were not used to compare cities. In genomics, papers from Holguin, Matanzas, and Sancti Spiritus received, on average, more citations than the world's papers did. In health biotechnology, this was the case for Matanzas and Sancti Spiritus.

Table XXXI Most active Cuban cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
Havana	300	0.67	0.60	212	0.57	0.60
Camaguey	11	0.77	0.45	2	n.s.	0.45
Holguin	6	n.s.	5.25	0		5.25
Ciego de Avila	5	n.s.	0.75	2	n.s.	0.75
Sancti Spiritus	3	n.s.	1.63	2	n.s.	1.63
Playa	3	n.s.	0.30	1	n.s.	0.30
Matanzas	2	n.s.	2.72	2	n.s.	2.72
Santiago de Cuba	2	n.s.	0.00	1	n.s.	0.00
Santa Clara	2	n.s.	0.52	0		0.52

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Table XXXII shows that most scientific activity in Cuba is concentrated in the government. Overall, three governmental institutions published more papers than the country's average for most active institutions in genomics, while five governmental institutions and one university did so in health biotechnology. However, among these institutions, the Centro de Ingenieria Genética y Bioteconología accounts for half of Cuba's production in both domains on its own, with 174 papers in genomics and 119 papers in health biotechnology. By comparison, the second most productive institution published 31 papers in genomics and 28 papers in health biotechnology, a mere 17% and 24%, respectively, of the Centro de Ingenieria Genética y Bioteconología's output. The country's most prolific university, the Universidad de la Habana, published 18 papers in genomics and 17 papers in health biotechnology. As was the case for cities, the ARIF was not of great relevance, due to the small number of papers published per institution. Institutions that had enough papers to allow a calculation of the ARIF all had similar values, both in genomics and health biotechnology, with their papers having, on average, an impact factor of about 50% of that of the world's papers. In genomics, papers from the Hospital "Lenin", the Centro Nacional de Genética Médica, the Centro Nacional de Sanidad Agropecuaria, and the Centro de Química Farmacéutica received, on average, more citations than the world's papers did. In health biotechnology, this was the case for the Pan American Health Organization and the Centro Nacional de Sanidad Agropecuaria. José de la Fuente (Centro de

Ingeniería Genética y Biotecnología) is clearly the leading researcher in Cuba, with 30 papers in genomics and 20 papers in health biotechnology.

Table XXXII Most active Cuban institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
Universidad de La Habana	18	0.51	0.52	17	0.44	0.36
Centro de Bioplasmas - Universidad de Ciego de Ávila	4	n.s.	0.94	2	n.s.	1.03
Government						
Centro de Ingeniería Genética y Biotecnología	174	0.64	0.47	119	0.65	0.52
Centro Nacional de Investigaciones Científicas	31	0.48	0.18	18	0.54	0.21
Instituto de Medicina Tropical "Pedro Kourí"	29	0.51	0.59	26	0.45	0.49
Centro de Inmunología Molecular	7	0.94	0.48	28	0.42	0.36
Instituto Finlay	11	0.58	0.71	7	n.s.	0.58
Instituto Cubano de Investigaciones de los Derivados de la Caña de Azúcar	8	n.s.	0.28	3	n.s.	0.09
Centro de Química Farmacéutica	7	n.s.	1.14	3	n.s.	0.16
Instituto de Hematología e Inmunología	9	n.s.	0.48	3	n.s.	0.29
Centro Nacional de Biopreparados	7	n.s.	0.27	1	n.s.	0.00
Instituto Nacional de Oncología y Radiobiología	4	n.s.	0.43	4	n.s.	0.08
Centro Nacional de Genética Médica	7	n.s.	1.65			
Havana Centro de Inmunoensayo				7	n.s.	0.22
Centro Nacional de Sanidad Agropecuaria	5	n.s.	1.20	3	n.s.	1.10
Clinics & Hospitals						
Hospital Hermanos Ameijeiras	5	n.s.	0.77	5	n.s.	0.15
Hospital "Lenin"	5	n.s.	6.30			
Hospital Pediátrico Docente "Juan Manuel Marquez"	4	n.s.	0.41	1	n.s.	1.03
Other						
Pan American Health Organization	2	n.s.	1.93	2	n.s.	1.96

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5.3.4 Egypt

With 253 papers in genomics and 91 papers in health biotechnology, Cairo is the most active city in Egypt (Table XXXIII). Other leading cities that published more papers than the country's average for most active cities include Alexandria (2nd place), Giza (3rd) and Mansour (4th). On average, none of the leading cities had papers with an impact factor greater than that of the world's papers. These cities had similar ARIFs, except for Mansour (ARIF of 1.05), whose papers in health biotechnology had, on average, impact factors similar to that of the world's papers. In terms of ARC, leading cities had similar values and their papers, on average, did not receive more citations than world's papers did. It is worth noting that, although Mania is not among the leading cities of Egypt in terms of number of

papers, it ranks 1st in genomics in terms of ARIF and 1st in genomics and health biotechnology in terms of ARC.

Table XXXIII Most active Egyptian cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
Cairo	253	0.74	0.59	91	0.72	0.43
Alexandria	102	0.63	0.38	20	0.72	0.31
Giza	62	0.56	0.38	21	0.70	0.35
Mansour	41	0.71	0.49	12	1.05	0.23
Tanta	33	0.72	0.74	7	n.s.	0.45
Assiut	20	0.70	0.39	11	0.55	0.05
Ismailia	23	0.60	0.76			
Zagazig	17	0.42	0.19	3	n.s.	0.00
Menia	11	0.98	0.80	2	n.s.	0.95
Menoufia	10	0.39	0.22	1	n.s.	0.27
Sohag	10	0.36	0.20	2	n.s.	0.34
Shibin al Kawm	9	n.s.	0.29	1	n.s.	0.00
Dokki	6	n.s.	0.30	1	n.s.	0.35
Kafr al Sheikh	6	n.s.	0.06			
Aswan	5	n.s.	0.09			

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

In Egypt, the main institutions contributing to genomics and health biotechnology publications come from the university and governmental sectors (Table XXXIV). Overall, four universities and one governmental institution published more papers than the country's average for the most active institutions in genomics and five universities and one governmental institution did so in health biotechnology. Among these institutions, the Cairo University ranks 1st in genomics, with 123 papers, and 1st in health biotechnology, with 33 publications. The National Research Center is the leading institution within the government, ranking 4th in genomics and 3rd in health biotechnology overall. The Menia University, although not among the leading institutions in terms of paper productivity, has the highest ARIF in genomics.

In health biotechnology, the Mansoura University, which ranks 5th in terms of number of publications, has an ARIF of 1.05, making it the only institution whose papers have, on average, a greater impact factor than the world average. Clinics and hospitals and other institutions do not make a major contribution to Egyptian genomics and health biotechnology publications. However, these sectors included the only institutions whose papers in genomics received, on average, more citations than the world average. Indeed, the Egyptian Society of Clinical Chemistry, the Tanta University Hospital, and the Cairo Liver Center all had an ARC above one. However, in their cases, ARCs are based on fewer than five publications; therefore, they do not reveal a general trend of

citations. No institutions had ARCs above one in health biotechnology. At the researcher level, there are no clear leaders in Egypt.

Table XXXIV Most active Egyptian institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
Cairo University	123	0.59	0.51	33	0.69	0.50
Alexandria University	94	0.62	0.38	15	0.74	0.40
Ain Shams University	82	0.80	0.57	29	0.77	0.51
Mansoura University	40	0.74	0.48	12	1.05	0.23
Tanta University	33	0.60	0.37	7	n.s.	0.45
Assiut University	22	0.63	0.69	9	n.s.	0.07
Al Azhar University	27	0.65	0.57	11	0.81	0.50
Suez Canal University	27	0.54	0.68	1	n.s.	0.00
Minufiya Univeristy	24	0.40	0.28	2	n.s.	0.14
Zagazig University	20	0.43	0.19	4	n.s.	0.92
Menia University	12	0.93	0.73	2	n.s.	0.95
Government						
National Research Centre	68	0.77	0.59	21	0.52	0.23
Agricultural Research Center (ARC)	15	0.66	0.33	2	n.s.	0.00
Theodor Bilharz Research Institute	10	0.67	0.53	8	n.s.	0.29
Ministry of Agriculture and Land Reclamation	4	n.s.	0.34	1	n.s.	0.58
Mubarak City for Scientific Research and Technology Applications (MUCSAT)	2	n.s.	0.00	3	n.s.	0.00
National Center for Radiation Research and Technology				4	n.s.	0.05
Clinics & Hospitals						
Cairo Liver Center	4	n.s.	1.78			
Tanta University Hospital	3	n.s.	2.41			
Other						
The Egyptian Society of Clinical Chemistry	1	n.s.	3.32	4	n.s.	0.97
Institut de recherche pour le développement	4	n.s.	0.17			

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5.3.5 India

Table XXXV shows that, in India, New Delhi, with 1,294 papers in genomics and 429 papers in health biotechnology, is the most active city. Its scientific papers were, on average, published in journals with smaller impact factors than the world average, but the city ranks well within India nonetheless. Indeed, in terms of ARIF, New Delhi ranks 4th in genomics and 3rd in health biotechnology. In terms of ARC, New Delhi is again 4th in genomics and in health biotechnology (about the same as Kolkata). Other cities that published more than the country average for the most active cities in genomics include Bangalore (2nd), Kolkata (3rd), Hyderabad (4th), and Mumbai in (5th).

Although Pune and Chandigarh did not publish more than the country average for the most active cities, they performed fairly well when the ARIF and the ARC are taken into account. When considering the ARIF, Pune ranks 2nd in both genomics and health biotechnology, and Chandigarh is tied with Pune in genomics and ranks 1st in health biotechnology. In terms of the ARC, Pune ranks 1st in genomics and 2nd in health biotechnology, and Chandigarh ranks 5th in genomics and 1st in health biotechnology.

Table XXXV Most active Indian cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
New Delhi	1,294	0.61	0.45	429	0.68	0.54
Bangalore	700	0.66	0.37	173	0.56	0.39
Kolkata	595	0.59	0.39	133	0.58	0.55
Hyderabad	471	0.59	0.41	102	0.58	0.40
Mumbai	437	0.53	0.27	122	0.50	0.23
Chennai	314	0.58	0.52	101	0.44	0.33
Pune	266	0.63	0.53	102	0.71	0.48
Lucknow	251	0.50	0.27	52	0.47	0.36
Chandigarh	170	0.63	0.43	94	0.80	0.64
Varanasi	166	0.40	0.18	34	0.60	0.38
Madurai	119	0.54	0.47	42	0.46	0.32
Patancheru	127	0.59	0.43	6	0.45	0.33
Izatnagar	114	0.27	0.20	41	0.36	0.25
Thiruvananthapuram	82	0.46	0.33	38	0.50	1.05
Karnal	94	0.23	0.06	18	0.31	0.42

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

In India, five universities, four governmental institutions, and one centre in the “other” category are in the top ten in genomics, with respect to the number of publications (Table XXXVI). In health biotechnology, the top ten includes four universities, five governmental institutions, and one centre in the “other” category. With 524 papers in genomics and 117 papers in health biotechnology, the most active institution, the Indian Institute of Science, is from the university sector. However, when grouping institutes from the same governmental entity, the Council of Scientific & Industrial Research (CSIR) ranks 1st (565 papers in genomics and 185 papers in health biotechnology), followed by the Indian Institute of Science, and the Indian Council of Agricultural Research (ICAR). When taking into account the ARIF and the ARC, the Indian Institute of Technology, Delhi, performs well in genomics, and the Institute of Microbial Technology – CSIR performs well in health biotechnology. Indeed, the Indian Institute of Technology, Delhi, ranks 1st with respect to both indicators in genomics; papers from this institution received, on average, 16% more citations than the world’s papers did. In health biotechnology, the Institute of Microbial Technology – CSIR ranks 1st in terms of ARIF and 2nd with respect to the ARC. Papers from this institute were published in journals that had, on average, impact factors similar to the average for the world’s papers.

Table XXXVI Most active Indian institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
Indian Institute of science	524	0.66	0.38	117	0.55	0.32
All India Institute of Medical Sciences	237	0.65	0.55	71	0.75	0.56
University of Delhi	196	0.52	0.42	64	0.54	0.50
Jawaharlal Nehru University	192	0.70	0.44	50	0.79	0.61
Banaras Hindu University	163	0.41	0.19	34	0.60	0.38
University of Madras	128	0.58	0.57	22	0.21	0.07
Madurai Kamaraj University	113	0.52	0.34	41	0.43	0.30
Punjab Agricultural University	76	0.37	0.18	29	0.49	0.32
Aligarh Muslim University	87	0.36	0.22	9	n.s.	0.33
University of Hyderabad	80	0.58	0.39	12	0.31	0.08
University of Calcutta	76	0.47	0.17	13	0.53	0.12
Osmania University	59	0.37	0.21	20	0.62	0.39
Indian Institute of Technology, Delhi	29	0.83	1.16	53	0.72	0.40
Govind Ballabh Pant University of Agri. & Tech.	58	0.24	0.15	13	0.49	0.51
Haryana Agricultural University	42	0.32	0.22	22	0.26	0.25
Government						
National Institute of Immunology	205	0.66	0.38	103	0.70	0.42
Centre for Cellular and Molecular Biology - CSIR	209	0.69	0.44	32	0.73	0.48
National Chemical Laboratory - CSIR	163	0.71	0.61	54	0.84	0.53
Indian Institute of Chemical Biology	157	0.70	0.33	25	0.62	0.36
Indian Veterinary Research Institute - ICAR	137	0.28	0.26	72	0.37	0.26
India Agricultural Research Institute - ICAR	139	0.37	0.25	20	0.32	0.28
Bhabha Atomic Research Centre	118	0.47	0.20	36	0.42	0.26
Tata Institute of Fundamental Research	125	0.80	0.41	14	0.85	0.42
Institute of Microbial Technology - CSIR	79	0.75	0.56	54	1.01	0.87
Nat'l Insti. of Cholera & Enteric Diseases - ICMR	76	0.68	0.66	28	0.71	0.49
Indian Council of Medical Research (ICMR)	69	0.59	0.31	26	0.54	0.33
Central Drug Research Institute - CSIR	71	0.59	0.23	15	0.56	0.16
Council of Scientific & Industrial Research (CSIR)	43	0.59	0.26	30	0.46	1.08
Saha Institute of Nuclear Physics	63	0.50	0.15	2	n.s.	0.00
Central Food Technological Research Institute	26	0.54	0.27	42	0.66	0.29
National Dairy Research Institute - ICAR	50	0.30	0.05	12	0.30	0.24
Clinics & Hospitals						
Tata Memorial Centre	100	0.40	0.24	36	0.40	0.13
Postgraduate Inst. of Medical Education & Res.	77	0.54	0.42	28	0.54	0.26
Christian Medical College	31	0.45	0.38	13	0.45	0.48
King Edward Memorial Hospital	17	0.55	0.34	1	0.55	0.00
Kasturba Hospital	14	0.37	0.19	1	0.37	0.00
Diabetes Research Centre	13	0.76	0.83		0.76	
Medical and Vision Research Foundation	13	0.61	0.61	8	0.61	0.80
Company						
Hindustan Lever Limited	5	n.s.	0.02	5	n.s.	0.08
AstraZeneca	3	n.s.	0.25	3	n.s.	0.84
Maharashtra Hybrid Seed Company	4	n.s.	0.38			
Other						
Int'l Centre for Genetic Engineering and Biotech	153	0.78	0.47	52	0.80	0.59
Int'l Crops Research Inst. Semi-Arid Tropics	129	0.60	0.44	6	n.s.	0.33
Bose Institute	114	0.65	0.33	34	0.66	0.25
Indian statistical Institute	64	0.64	0.44	5	n.s.	0.06
Centre for Biochemical Technology	45	0.49	0.22	9	n.s.	0.52
Jawaharlal Nehru Centre for Adv. Scientific Res.	42	0.82	0.46	5	n.s.	0.67
Tata Energy Research Institute	35	0.56	0.50	7	n.s.	0.19

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5.3.6 Republic of Korea

In South Korea, Seoul is the clear leader in both genomics and health biotechnology, publishing about 50% of the country's papers in both domains (Table XXXVII). The second city in importance, and the only other city to have published more papers than the country's average for leading cities, is Taejon, having published a third of the number of Seoul's publications in genomics and half of its papers in health biotechnology. There is little variation among cities in terms of the ARIF and ARC in genomics and health biotechnology. However, Pohang ranks 1st in genomics, with respect to both indicators, indicating that the quality of its papers is greater than the country's average.

Table XXXVII Most active South Korean cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
Seoul	3,810	0.75	0.64	1,155	0.73	0.59
Taejon	1,223	0.72	0.57	579	0.71	0.59
Kwangju	421	0.76	0.52	115	0.68	0.51
Pusan	319	0.68	0.51	111	0.65	0.45
Taegu	320	0.67	0.57	92	0.67	0.71
Pohang	243	0.92	0.73	58	0.69	0.51
Chunchon	194	0.57	0.53	77	0.54	0.42
Chinju	205	0.65	0.61	53	0.65	0.52
Jeonju	190	0.72	0.58	61	0.75	0.47
Cheonan	109	0.72	0.45	41	0.52	0.46
Cheongju	106	0.77	0.65	43	0.73	0.39
Yongin	105	0.63	0.68	32	0.48	0.86
Kyongsan	90	0.63	0.39	34	0.66	0.51
Kyonggi Do	78	0.67	0.54	47	0.70	0.49
Ulsan	66	0.60	0.33	17	0.75	0.32

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Seoul National University is clearly the country's publications leader: 1,587 papers in genomics and 471 papers in health biotechnology (Table XXXVIII). The 2nd most active institution in both domains is governmental. The Korea Research Institute of Bioscience and Biotechnology has published 526 papers in genomics and 284 papers in health biotechnology. This relatively high output puts this governmental institution within the exclusive academic top ten leaders of the country. 3rd place is occupied by Yonsei University, Korea University ranks 4th, and Chungbuk National University is 5th. The Seoul University Hospital leads the health sector in both domains. The Pohang University of Science and Technology has performed very well in terms of its ARIF in genomics, with a score of 0.95. In health biotechnology, the University of Ulsan and the Catholic University of Korea tended to publish in high-impact journals, with respective ARIFs of 0.94 and 0.92. Among developing countries, Korean companies are the most active in peer-reviewed publishing. Leaders are LG Chem Ltd, the Korea Kumho Petrochemical Company, and the Hanhyo Institute of Technology.

Table XXXVIII Most active South Korean institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
Seoul National University	1,587	0.78	0.61	471	0.75	0.56
Korea Advanced Institute of S&T	477	0.78	0.62	267	0.83	0.76
Yonsei University	484	0.77	0.65	158	0.82	0.76
Korea University	396	0.63	0.51	132	0.63	0.39
Chungbuk National University	310	0.69	0.48	102	0.65	0.55
Catholic University of Korea	272	0.88	0.91	55	0.92	1.33
Chonnam National University	261	0.80	0.59	69	0.61	0.57
Pohang University of Science and Technology	246	0.95	0.78	58	0.70	0.53
Sungkyunkwan University	253	0.83	0.74	60	0.66	0.41
Kyungpook National University	221	0.61	0.58	69	0.62	0.72
Gyeongsang National University	224	0.72	0.68	56	0.68	0.44
University of Ulsan	195	0.77	0.67	45	0.94	0.74
Inha University	171	0.70	0.47	58	0.60	0.43
Kyung Hee University	160	0.64	0.41	54	0.60	0.36
Hallym University	148	0.63	0.55	43	0.58	0.46
Pusan National University	144	0.69	0.55	50	0.64	0.59
Ajou University	152	0.77	0.60	48	0.84	0.63
Hanyang University	139	0.55	0.48	45	0.59	0.24
Ewha Womans University	129	0.65	0.44	23	0.60	0.39
Yeungnam University	109	0.71	0.46	21	0.72	0.29
Chonbuk National University	102	0.74	0.52	33	0.73	0.53
Kangweon National University	89	0.52	0.42	43	0.58	0.47
Wonkwang University	97	0.69	0.53	23	0.60	0.83
Government						
Korea Research Inst. of Bioscience and Biotech.	526	0.68	0.55	284	0.61	0.44
Ministry of Agriculture and Forestry	76	0.62	0.66	28	0.50	0.44
Korean National Institute of Health	60	0.61	0.46	12	0.60	0.57
Korea Institute of Science and Technology	39	0.56	0.61	19	0.60	0.31
National Institute of Agricultural S&T	40	0.68	0.56	12	0.45	0.60
Korea Basic Science Institute	29	0.74	0.38	1	n.s.	0.00
Korea Research Inst. of Chemical Technology	25	0.70	0.28	6	n.s.	0.39
Korea Food and Drug Administration	23	0.68	0.63	9	n.s.	0.73
Korea Atomic Energy Research Institute	16	0.57	0.24	7	n.s.	0.34
Korea Ginseng & Tobacco Research Institute	18	0.67	0.32	6	n.s.	0.25
National Cancer Center	20	0.98	0.94	7	n.s.	0.19
National Fisheries R&D Institute	15	0.59	0.17	3	n.s.	0.05
Clinics & Hospitals						
Seoul National University Hospital	118	0.79	0.54	25	0.81	0.48
Korea Cancer Center Hospital	57	0.76	0.48	15	0.88	0.61
Asan Medical Center	35	0.78	0.60	8	n.s.	0.57
Samsung Medical Center	26	1.13	0.79	5	n.s.	0.15
St Mary's Hospital	7	n.s.	0.13	7	n.s.	0.24
Kyung Hee University Hospital	11	0.41	0.63	1	n.s.	0.00
Company						
LG Chem Ltd.	34	0.70	0.67	24	0.88	0.78
Korea Kumho Petrochemical Company Ltd	30	0.92	0.45	3	n.s.	1.09
Hanhyo Institute of Technology	22	0.80	0.52	16	0.78	0.72
Samyang Genex Research Institute	12	0.58	0.34	9	n.s.	0.43
Cheil Jedang Corporation	12	0.43	0.06	8	n.s.	0.16
Daewoong Pharmaceutical Co. Ltd.	10	0.39	0.21	2	n.s.	0.28
Other						
Samsung Biomedical Research Institute	46	1.20	0.83	6	n.s.	0.55
Mogam Biotechnology Research Institute	28	0.74	0.78	22	0.76	0.83
Korean Institute of Tuberculosis	16	0.80	1.24	6	n.s.	0.72
Korea Ocean Research and Development Inst.	10	0.83	0.75	3	n.s.	0.38

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

5.3.7 South Africa

Johannesburg and Cape Town are clearly the two most active South African cities in genomics and health biotechnology, in terms of the absolute number of papers (more than 300 papers during the period). They are followed by Pretoria, Rondebosch, and Tygerberg (Table XXXIX). In terms of ARIF, Cape Town is the leader in genomics, followed by Johannesburg and Rondebosch. In health biotechnology, Stellenbosch ranks 3rd behind Johannesburg and Cape Town, and has produced about the same number of papers as Pretoria. Cities have about the same level of expected impact, except for Bloemfontein, with an ARIF of 0.95. Overall, Cape Town, Tygerberg, and Bellville have been cited the most in both domains.

Table XXXIX Most active South African cities in genomics and health biotechnology, 1991-2002

City	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
Johannesburg	380	0.85	0.83	71	0.74	0.64
Cape Town	357	0.90	0.87	66	0.82	1.03
Pretoria	261	0.67	0.65	52	0.73	0.51
Rondebosch	181	0.84	0.71	45	0.85	0.74
Tygerberg	181	0.78	0.84	34	0.84	1.45
Stellenbosch	141	0.76	0.64	57	0.84	0.88
Durban	105	0.73	0.74	24	0.90	0.63
Bloemfontein	98	0.65	0.46	48	0.95	0.73
Onderstepoort	91	0.76	0.63	36	0.80	0.49
Matieland	61	0.76	0.66	9	n.s.	0.87
Witwatersrand	47	0.81	0.48	18	1.23	0.53
Grahamstown	44	0.83	0.89	12	0.71	0.55
Bellville	38	1.15	1.16	5	n.s.	1.89
Observatory	31	0.72	0.63	8	n.s.	0.92
Congella	29	0.60	0.58	10	0.80	0.85
Pietermaritzburg	25	0.48	0.35	14	0.37	0.32

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

Leading institutions are principally from the academic sector. The four most prolific universities in both domains are the University of Cape Town, the University of the Witwatersrand, Stellenbosch University, and the University of Pretoria. Within the governmental sector, the South African Institute for Medical Research leads in genomics and the Onderstepoort Veterinary Institute (ARC) in health biotechnology. The efforts of the Agricultural Research Council's research institutes are making this department central to the government's scientific output in genomics. In the health sector, the most active institutions in genomics and health biotechnology are the Groote Schuur Hospital (affiliated to the University of Cape Town) and Tygerberg Academic Hospital (affiliated to the University of Stellenbosch). When looking at impact factors in genomics, the University of Western Cape has an ARIF above the world's average. The University of Cape Town and the South

African Institute of Medical Research had the highest ARIFs. The University of Cape Town and the University of Stellenbosch received the highest number of ARC for their papers in health biotechnology, a number that was just above the world average. Trefor Jenkins (University of the Witw) is the country's leading researcher in genomics, with 59 papers, while it is SI (Sakkie) Pretorius (Stellenbosch University) in health biotechnology, with 29 papers.

Table XL Most active South African institutions in genomics and health biotechnology, 1991-2002

Sector/Institution	Genomics			Health Biotechnology		
	Papers	ARIF	ARC	Papers	ARIF	ARC
University						
University of Cape Town	466	0.90	0.81	97	0.87	1.01
University of the Witwatersrand	375	0.87	0.78	85	0.83	0.59
Stellenbosch University	357	0.78	0.76	94	0.83	1.06
University of Pretoria	214	0.70	0.67	40	0.83	0.57
Natal University	113	0.60	0.53	37	0.56	0.40
University of the Free State	97	0.65	0.45	48	0.95	0.73
Rhodes University	41	0.87	0.92	12	0.71	0.55
University of the Western Cape	37	1.11	1.07	6	n.s.	1.57
Rand Afrikaans University	37	0.36	0.27			
University of Durban-Westville	27	0.54	0.23	5	n.s.	0.55
Medical University of Southern Africa	24	0.68	0.42	7	n.s.	0.40
Government						
South African Institute for Medical Research	154	0.91	0.97	22	0.83	0.70
ARC-Onderstepoort Veterinary Institute	83	0.73	0.59	30	0.81	0.52
Medical Research Council	54	0.84	0.78	15	0.82	0.90
National Institute for Communicable Diseases	28	0.67	0.65	10	0.71	0.75
Agricultural Research Council	18	0.53	0.45	1	n.s.	0.36
Provincial Laboratory for Tissue Immunology	16	1.12	0.56	3	n.s.	0.24
Council for Scientific and Industrial Research	13	0.84	0.41	4	n.s.	1.11
ARC-Roodeplaat Vegetable and Ornamental Plant Institute	13	0.26	0.44	3	n.s.	0.00
National Blood Transfusion Service	10	1.58	2.60	4	n.s.	0.10
Clinics & Hospitals						
Groote Schuur Hospital	58	0.75	0.63	19	0.70	0.87
Tygerberg Academic Hospital	40	0.71	0.96	10	0.39	0.57
Red Cross War Memorial Children's Hospital	22	0.69	1.00	4	n.s.	0.25
Chris Hani Baragwanath Hospital	15	0.84	0.86			
Johannesburg Academic Hospital	10	0.89	0.47	1	n.s.	0.00
Company						
Billiton Process Research				3	n.s.	0.00
Other						
National Botanical Institute	11	0.85	0.52			
Natal Institute of Immunology	9	n.s.	0.87	2	n.s.	0.73
Durban Natural Science Museum	7	n.s.	0.80			

Source: Compiled by Science-Metrix from data prepared by ISI Thomson.

6 Conclusion

This study focuses on health biotechnology and encompasses all fields of genome science. Developing countries often specialize in the fields of genomics, such as biological sciences and chemistry that could contribute to global health and sustainability. In particular, Biology is the field which all studied developing countries are all the most specialized. Within Biology, some developing countries specialize strongly in Agriculture & Food Science, Botany, and Dairy & Animal Science. Also noteworthy, is the high level of specialization in the field of Chemistry observed: Analytical Chemistry in China, Inorganic & Nuclear Chemistry in India, and Polymers in Republic of Korea.

Health-related genomics and biotechnology in developing countries are less clinically oriented, compared to leading developed countries. In fact, only Egypt specializes in Clinical Medicine in both domains, whereas Cuba specializes in health biotechnology.

The specialization index of developing countries within Biomedical Research and Clinical Medicine translate local priorities that reflect the particular environmental settings. For instance, Brazil is highly specialized in Parasitology and Tropical Medicine, South Africa in Virology, Microbiology and Veterinary Medicine, and India in Veterinary Medicine.

With the exception of Egypt, developing countries in this study were among the leaders in terms of growth of scientific output in genomics (5% to 22% growth) and in health biotechnology (10% to 25%) between 1999 and 2002. In general, international collaboration is more important than national collaboration (more than 40% of the genomics papers). However, this is not the case for the Republic of Korea, where national collaboration has been predominant since 1996. Similarly, national collaboration is rapidly becoming predominant in Brazil and China. This is likely an indication that the national research systems are more developed and cohesive in these countries. By contrast, Egypt and South Africa have a fairly high international collaboration rate, which can be seen as an indicator of dependence on international science. Indian researchers are more prone to perform individual work, as witnessed by the fact that India had the lowest international and national collaboration rates in genomics and in health biotechnology publications.

Overall, developing countries are rapidly increasing their presence in the life sciences' world scientific community. In particular, China and the Republic of Korea will enter the league of leading countries in the near future, and will overtake so-called developed countries in terms of absolute scientific output in genomics and health biotechnology. As the international community stresses the need to apply genomics and health biotechnology R&D to improve global health and sustainability in developing countries where poverty, disease, high population density and environmental problems are most prevalent, the next decade might provide developing countries with the necessary knowledge and know-how to solve these issues.