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PROFESSIONAL DOCTORATES IN BIOTECHNOLOGY: MAPPING AND TRENDS IN WORLD-CLASS UNIVERSITIES CONTEXTUALIZED IN INTERNATIONAL ACADEMIC RANKINGS

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ABSTRACT

Considering the recent operation of the first professional doctorates in Biotechnology (PDBs) in Brazil, starting in 2019, and the Brazilian government's efforts to boost priority areas for the country's scientific and technological development, this article aims to identify whether PDBs are courses commonly offered by the main universities in the world and analyze the trends of this type of doctorate in World-Class Universities (WCUs). The indicators adopted for the analysis of DPB were divided into two groups: a) mapping the geopolitics of DPB and b) characterization of the courses. This is an exploratory, analytical-descriptive, bibliographic and documentary study that could potentially support the expansion of PDBs in Brazil. Among other trends, the study demonstrated a reduced number of PDBs among the WCUs researched and showed that PDBs are a type of doctoral training of relatively recent creation worldwide.

KEYWORDS: Doctorate, Academic Doctorate, Professional Doctorate, Professional Doctorate in Biotechnology, Academic Doctorate in Biotechnology.

DOUTORADOS PROFISSIONAIS EM BIOTECNOLOGIA: MAPEAMENTO E TENDÊNCIAS EM UNIVERSIDADES DE CLASSE MUNDIAL CONTEXTUALIZADAS NOS RANKINGS ACADÊMICOS INTERNACIONAIS

RESUMO

Considerando o recente funcionamento dos primeiros doutorados profissionais em Biotecnologia (DPB) no Brasil, a partir de 2019, e ainda os esforços do governo brasileiro para impulsionar as áreas prioritárias para o desenvolvimento científico e tecnológico do país, o objetivo deste artigo foi identificar se os DPB são cursos comumente oferecidos pelas principais universidades do mundo e analisar as tendências desse tipo de doutorado nas chamadas Universidades de Classe Mundial (UCM). Os indicadores adotados para a análise dos DPB foram divididos em dois grupos: a) mapeamento da geopolítica dos DPB e b) caracterização dos cursos. É um estudo de natureza exploratória, analítico-descritiva, bibliográfica e documental, com o potencial de poder subsidiar a expansão dos DPB no país. Entre outras tendências, o estudo demonstrou o reduzido número de DPB entre as UCM pesquisadas, bem como o fato de também ser uma modalidade de formação doutoral de relativa recente criação em âmbito mundial.

Palavras chave: Doutorado, Doutorado Acadêmico, Doutorado Profissional, Doutorado Profissional em Biotecnologia, Doutorado acadêmico em Biotecnologia.

1. INTRODUCTION

Historically, the highest academic degree awarded by universities is the PhD, from the Latin Philosophiae Doctor. Since the consolidation of the German university model in the 19th century, this degree has been focused on the field of scientific research, traditionally referred to as the academic doctorate or research doctorate (Vieira Alves, 2022).

The expansion of the professional doctorate, as a doctoral training model with equal importance and equivalence to the PhD, has sparked numerous debates not only within academia but also in the formulation of university policies in various countries worldwide, such as Brazil and Mexico. These are the only Ibero-American countries that have created legislation aimed at establishing professional doctorates within their higher education systems (Fruchi et al., 2024).

According to Bourner, Bowden and Laing (2001), although the professional doctorate emerged in the United States in 1921, at Harvard University, it was only in the beginning of the 1990s that we witnessed exponential growth in professional doctorates in several universities of the Anglo-Saxon world. During this period, the professional doctorate began to be seen as an alternative doctoral training and an educational model focused on the relationships between the university, industry (or the workplace) and professional practice (Maxwell, 2003).

Fell, Flint and Haines (2011) state that while the traditional doctorate is training for a career in (academic) research, the Professional Doctorate is concerned with the development of practice and professional identity.

The Professional Doctorate by nature is concerned with professionals who develop their work up to the doctorate level, working in partnership with a university to develop new knowledge and innovative approaches in their workplace (Fulton et al., 2012). The new market demands require professionals to have multidisciplinary training, the ability to handle different technologies, innovative and creative attitudes, and to be constantly seeking qualification (Souza & Souza, 2018).

Although increasing the company's profits is not the initial explicit objective, the professional academic training involved ends up becoming beneficial for the sponsoring organization and, as a result, increases productivity and economic income (Fulton et al., 2012).

Thus, considering the combination of the educational and industrial environments, it can be observed that the Professional Doctorate (PD) is a vehicle that brings together the state-of-the-art of professional practice with relevant academic theory applied to solving work-related problems, which generates a change in the student's own workplace (Maxwell 2003, Lee & Brennan, 2000). The PD is interdisciplinary and recognizes that real-world problems inhabit a dynamic, multifaceted, and complex space.

The creation of professional doctorates is relatively recent when compared to the expansion of programs that began in the Anglophone world starting in the 1990s and gaining more momentum in the early 2000s (Bourner; Bowden; Laing, 2001).

In Brazil, even with the advisory opinion of the Federal Education Council (CFE) nº 977/65, which already proposed the creation of postgraduate courses aimed at professional training (Silva & Del Pino, 2016), it was only from 2017 onwards that this doctoral modality began to be recognized and regulated by the Ministry of Education (Brasil, 2017a; Brasil, 2017b).

As postulated by the Ministry of Science, Technology and Innovation (MCTI, acronym in Brazilian Portuguese) and with the aim of "contributing to leverage sectors with greater potential for accelerating economic and social development in Brazil", it is necessary to develop a competitive applied science that positions the country in a strategic place in geopolitical terms

(Brasil, 2020, p. 19). The implementation of consistent professional doctorate courses that truly contribute to priority areas for the country's scientific and technological development, specifically in the area of enabling technologies: artificial intelligence, internet of things, advanced materials, biotechnology and nanotechnology (Brasil, 2020), has been a challenge for the government, industry and the academic community.

These challenges in order to meet government demands in areas considered strategic, including alignment pressures on the part of Human Sciences researchers, are considered, by Silva Junior, Ferreira and Kato (2013, p. 452), as a new Brazilian scientific sociability that stems, among other factors, from the strong “induction of research via financing and evaluation processes”.

These priority areas include the study of Biotechnology, which, as Faleiro, Andrade and Reis Junior (2011, p. 13) point out, "is a set of techniques that uses living beings, or part of them, in the development of processes and products that have an economic and (or) social purpose".

Biotechnology arises from the interaction between basic science (molecular biology, microbiology, cell biology, genetics, etc.), applied science (immunological and biochemical techniques, as well as techniques arising from physics and electronics), and other technologies (fermentations, separations, purifications, IT, robotics and process control). In this context, biotechnology is broadly considered as a science based on multidisciplinary knowledge that uses biological agents to make useful products or solve problems (Malajovich, 2016).

Therefore, given the growing demand for the development of new technologies, the Professional Doctorate in Biotechnology (PDB) becomes a solution for training new professionals in response to the growing demands generated by industry 4.0 in Brazil and the world[1].

Industry 4.0, like biotechnology, is based on technologies, smart objects and the internet of things in order to build systems capable of self-management, enabling greater customization of products without losing the advantages of mass production (Lasi et al., 2014). Industry 4.0 enables the integration of humans and machines, even if in distant geographic locations, enabling the formation of large networks, providing products and services autonomously (Silva; Santos Filho; Myagi, 2015).

This study searches for possible answers and/or data to the following questions:

1. Despite its recent creation, what are the PDBs existing in Brazil?
2. What are the trends in terms of objectives, area of concentration, time for completion, cooperation projects with strategic partners and final assignment to obtain the PDB title?
3. What are the main universities in the world, legitimized by international academic rankings, also known as world-class universities (WCUs) (Lourenço; Calderón, 2015; Ganga-Contreras et al., 2020), that offer PDB courses?
4. Is there a temporal discrepancy between the creations of professional doctorates at WCUs and at Brazilian universities?
5. In the context of PDBs in WCUs, what are the main characteristics of these courses and

[1]Constant transformations, market development and growing competitiveness led to the emergence of the so-called Fourth Industrial Revolution (Piccarozzi; Aquilani; Gatti, 2018). The fourth industrial revolution is based on the development of fully automated and intelligent production, capable of communicating autonomously with the main corporate actors (Li; Hou; Wu, 2017). This new paradigm, called Industry 4.0, is based on the advanced digitalization of factories, the Internet and future-oriented technologies (Lasi et al., 2014). In short, Industry 4.0 is a generic term for a new industrial paradigm that encompasses a set of future industrial developments related to enabling technologies (Weyer et al., 2015).

what are the main trends in terms of convergences and specificities when comparing the PDBs offered by different WCUs?

6. What are the countries of origin of these courses, areas of concentration or thematic focus of the courses offered?
7. What are the characteristics of these courses in terms of functioning, taking as a reference: admission criteria, prerequisites, time for completion, financing and partnerships of the universities found?

In this scenario, this article aims to study, within a comparative perspective, the convergences, specificities and main trends that exist between WCUs, legitimized by the main international academic rankings, in the offer of Professional Doctorates in the area of Enabling Technologies, specifically in the area of Biotechnology.

The policy of incipient creation and expansion of PDB justifies the academic-scientific relevance of this article, whose applied nature can potentially subsidize the implementation of PDB in Brazil in the light of PDB experiences offered by WCUs, through the exercise of Benchmarking, a process considered by Hazelkorn (2014) as a comparison and assessment of quality and performance in peer countries and institutions as part of a strategic or political approach to improvement, highlighting similarities and differences through the analysis of comparable data or through more informal mechanisms.

In methodological terms, this is essentially exploratory, analytical-descriptive research. The exploratory nature is evident insofar as we are investigating a relatively new and little-studied subject or topic, with relatively little academic literature, in which it is difficult to start a priori with more solid and consistent hypotheses (Piovesan; Temporini, 1995, p 319). The strong descriptive component is evident in the very nature of exploratory research (Piovesan; Temporini, 1995, p. 319), which provided data that allowed consistent analyses to be carried out.

The exploratory nature of this study is coupled with the adoption of analysis strategies in the field of comparative education. Highlighting that, as Ferreira (2008) notes, comparative education is a multidisciplinary component of the Educational Sciences that comparatively examines dynamics of the educational process considering diverse contexts defined by time and/or space, aiming to attain knowledge that would not be possible through the analysis of a single situation. In this sense, we initially performed compartmentalized analyses of the units to be compared, and later carried out horizontal crossings that made it possible to find convergences, common denominators, as well as differences in approaches to the topic in focus. In the study of the PD adopted by WCUs, descriptive and explanatory approaches were used, discarding any type of subjective-impressionist approach.

Initially, a bibliographical survey was carried out on specific scientific production about PDB. We identified that such literature is quite limited; however, a refined survey was carried out to analyze the data generated in this study.

National and international databases were searched, such as Scielo – Scientific Electronic Library Online; Redalyc – Red de Revistas Científicas de América Latina y el Caribe, España y Portugal; Portal de Periódicos da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), an organization linked to the Brazilian Ministry of Education that allows access to the Scopus and Web of Science databases. The investigation was based on the search for the following descriptors: Doctorate, Academic Doctorate (ACD), Professional Doctorate (PD), Professional Doctorate in Biotechnology (PDB) and Academic Doctorate in Biotechnology (ACDB).

To identify the WCUs that served as the basis for the study, the universities that appear

simultaneously in the three main international rankings were initially taken as a reference: Academic Ranking of World Universities (ARWU); Time Higher Education World University Ranking (THE) and Quacquarelli Symonds World University Ranking (QS) (Lourenço; Calderón, 2015; Ganga-Contreras et al., 2020)[2].

The use of these three rankings as a reference for this study was based on the results of the study "Rankings in institutional strategies and processes", the first pan-European study on the impact and influence of rankings in European higher education institutions (Hazelkorn; Loukkola; Zhang, 2014). In it, the informants, managers of the universities that participated in the research, highlighted these three rankings as the "most influential or those they consider to have the greatest impact on them" (Hazelkorn; Loukkola; Zhang, 2014, p. 26), for these rankings focus "exclusively on a select group of elite, research-intensive universities, accessible only to a small fraction of the post-secondary student population" (Hazelkorn; Loukkola; Zhang, 2014, p. 21).

Therefore, the 45 best universities were initially selected, according to each ranking mentioned, with the year 2022 as a reference, and a comparative list was subsequently carried out to identify the universities that appear in the three rankings. Considering the small number of PDBs found in the researched WCUs and in order to exhaust sample data, we extended our search to the first 100 universities in the aforementioned rankings using specific rankings by subject areas. Among the three rankings researched, only the ARWU, presents in its list of universities the Subject field of Biotechnology.

With the list of WCUs in hand, searches were carried out on the websites of all selected universities, to check which of them offer PDB, also taking as a reference the following analytical indicators divided into two groups:

a) Mapping the geopolitics of the PDB: Name of world-class universities that offer professional doctorates, country of origin and name of the course offered.
b) Characterization of the courses: admission criteria, prerequisites, time of completion, financing and partnerships of the universities found.

All data that supported the aforementioned analytical indicators were obtained, cataloged and systematized based on a detailed and careful search carried out on the electronic pages of each of the WCUs that make up the sample.

In all searches, the quality of the information available on the electronic pages of the professional doctorates offered was checked, taking all precautions with regard to the organization of web-found information and in selecting information units that end up generating document chains. To analyze and interpret the collected data, we will carry out three fundamental steps: classify, code and tabulate.

Data that were not included or were not clear on the electronic pages of the selected sample were requested through electronic messages from all PDB surveyed. All information was cataloged according to the indicators adopted in this research, recording the start and end dates

[2]Regarding the mentioned rankings, based on Ganga-Contreras *et al.* (2020), it is worth mentioning that the *Academic Ranking of World Universities* is published annually by the Shanghai Ranking consultancy, its first edition was launched in 2003, becoming a pioneer in the development of university listings around the world, using objective information focused on concrete products of university work, essentially quantitative data, predominantly on scientific research. The *World University Rankings,* produced since 2004 by the English magazine Times Higher Education, uses a relative balance between objective and subjective indicators, considering differences among others. The QS ranking - *World University Rankings,* produced annually by the company Quacquarelli Symonds from the United Kingdom, bases 50.0% of its assessment of universities on subjective data resulting from questionnaires applied to both academics and employers, with the aim of evaluating the university's reputation.

of the different moments of data collection.

With the data in hand, a comparative exercise began between PDBs to then analyze the data in the light of contemporary literature and the Brazilian experience in the implementation of professional doctorates.

2. RESULTS AND DISCUSSION

PD programs are a growing reality in Brazil. However, as in other regions of the world, important discrepancies persist in the geographic distribution of courses offered. Currently, there are a total of 58 graduate courses in the PD modality recognized by the Ministry of Education (MEC) in Brazil, of which 5.18% (three courses) are in the central-west region, 18, 96% (11 courses) in the northeast region, 10.35% (six courses) in the north region, 41.37% (24 courses) in the southeast region and 24.14% (14 courses) in the south region.

As can be seen, the majority of PD courses are concentrated in the southeast and south of the country, representing 65.51% of the total, a fact that reflects regional asymmetries, as well as the way in which *stricto sensu* graduate courses have historically been distributed in Brazil, concentrated in regions with greater economic development, such as the southeast, considered the most economically developed and where a large part of the national industry is concentrated (BRASIL, 2012).

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It is worth highlighting that this situation still persists, despite the efforts of graduate public policies aimed at alleviating these regional asymmetries (Nazareno, Herbetta, 2019), and "we must not forget that the federative principle requires more balance and regional development is a constitutional principle" (Cury, 2004, p. 871).

Among the 58 PD courses available in the national territory, there were only five universities with a PDB doctoral modality (Chart 1): State University of Montes Claros (UNIMONTES) with the Professional Doctorate in Biotechnology; State University of Ceará (UECE) with the Biotechnology in Human and Animal Health course; São Paulo State University, Botucatu (UNESP) with the Research and Development course (Medical Biotechnology); Universidade Positivo (UP) with the Industrial Biotechnology course and Universidade Potiguar (UNP) with the Health Biotechnology course.

In Chart 1, it is possible to observe the characteristics of the PDBs existing in Brazil, in the period from 2019 to 2023: name, objective, area of concentration, time for completion and final assignment to obtain the PDB title recognized by the Ministry of Education in Brazil. This table makes it possible to analyze some variables between the five PDB courses available in Brazilian territory.

Chart 1: Characteristics of existing PDBs in Brazil (2017-2023) - name, objective, area of concentration, time for completion, cooperation projects and final assignment to obtain the PDB title.

State University of Montes Claros (UNIMONTES)	
Course name	Professional Doctorate in Biotechnology
Year of creation	2019
Objective	Training of human resources aimed at developing scientific activities to generate innovative products and processes for the pharmaceutical, food and energy production industries
Concentration area	Industrial Biotechnology and Genetic Resources
Time/Completion	48 months
Final assignment to obtain the title	Dissertation/Thesis
State University of Ceará (UECE)	
Course name	Biotechnology in Human and Animal Health
Year of creation	2020
Objective	Training of qualified personnel for activities related to teaching and scientific research
Concentration area	Biotechnology in Health
Time/Completion	48 months
Final assignment to obtain the title	Dissertation/Thesis
São Paulo State University, Botucatu (UNESP-BOT)	
Course name	Research and Development (Medical Biotechnology)
Year of creation	2019
Objective	Providing the necessary improvement for the exercise of transformative and cutting-edge professional practice, in an articulated and integrated way.
Concentration area	Biotechnology
Time/Completion	48 months
Final assignment to obtain the title	Dissertation/Thesis
Universidade Positivo (UP)	
Course name	Industrial Biotechnology
Year of creation	2019
Objective	Training of doctors in Biotechnology and providing conditions so that professionals can update themselves scientifically, pedagogically and professionally.
Concentration area	Health, Agrifood and Environmental
Time/Completion	48 months
Final assignment to obtain the title	Dissertation/Thesis
Universidade Potiguar (UNP)	
Course name	Health Biotechnology
Year of creation	2019
Objective	Training of qualified professionals to carry out advanced professional practice and transform bioproducts and bioprocesses.
Concentration area	Health Biotechnology
Time/Completion	48 months
Final assignment to obtain the title	Dissertation/Thesis

Source: Prepared by the author, 2023.

It is observed that PDB courses focus on four specific areas: Biotechnology, Human and Animal Biotechnology, Medical Biotechnology and Industrial Biotechnology, proving to be a versatile and growing field of study. In Brazil, PDB researches not only Human Biotechnology, but also Animal Biotechnology; not only medical, but also industrial. As for the area of concentration, the wide window of research possibilities is clear, such as Industrial Biotechnology, Genetic Resources, Health Biotechnology, and Agrifood and Environmental Biotechnology.

Another significant difference between the courses is in relation to the objectives of the different institutions with PDB. While UNIMONTES, UNESP and UNP aim to develop innovative products and processes linked to professional practice, UECE's program focuses on training qualified personnel for activities related to teaching and scientific research. On the other hand, UP presents an alternative, or synthesis, of both scopes. Its objective is to train doctors in Biotechnology, providing conditions for professionals to update themselves scientifically, pedagogically and professionally.

In a comparative exercise between Brazilian universities that have a PDB course, it is observed that Brazil only had its first PDB in 2019, that is, seventeen years after the creation of the first PDB in WCUs, specifically at Imperial College London, which had its professional doctorate in *Biomedical engineering and industrial biotechnology* created in 2002 (Chart 2). However, it is worth highlighting that in Brazil, the first professional master's degree was created in 2000, two years before the PDB at Imperial College London, with the beginning of the professional master's degree in Research and Development (Medical Biotechnology) at UNESP-BOT.

Regarding the time for course completion, there was no difference between universities, varying between a minimum of 24 months (2 years) and a maximum of 48 months (or up to 4 years).

A noteworthy aspect of these five PDB courses is the fact that three of them explicitly mention on their institutional web pages the existence of cooperation projects with national and foreign non-academic institutions:

- Unimontes: Banco do Nordeste (regional development bank), CoopAPI (Agricultural Cooperative of Ilicínea), Codeanm (Municipal Council for Environmental Defense and Conservation of Montes Claros), Minarvm (R&D Startup in Biotechnology - Cosmetics) and Petrobras.
- State University of Ceará (UECE): Federal University of Piauí (UFPI), Teresina-PI; Worker Cooperative of General Surgeons of Ceará (COOCIRURGE); Vital Brazil Institute (IVB); Oswaldo Cruz Foundation - Ceará (FIOCRUZ-CE), Fortaleza-CE; Clinicardio – JAC Métodos Diagnósticos SS (Cardiology clinic); Centro de Pesquisas em Doenças Hepato Renais do Ceará (Research center for hepatorenal diseases); The National Institute for Agrarian and Veterinary Research, I.P. Avero Portugal, and National Service for Rural Learning - Regional Administration of the State of Ceará (SENAR-AR/CE).
- São Paulo State University, Botucatu (UNESP-BOT): Instituto de Medicina Molecular (Institute of Molecular Medicine) and startup TechnoPhage from Lisbon, Portugal; Laboratoire de Virologie, Center HospitalierUniversitaire (CHU), Montpellier, France; Center Interuniversitaire de Rechercheet d'Ingénieriedes Matériaux, Université de Toulouse; Center d'Elaboration de Matériaux et d'Etudes Structurales, CNRS le Laboratoire de Génie Chimique, UMR-CNRS 5503, Université Paul Sabatier;

University of Toronto, Canada; Institute National de Trannfusion Sanguine de Paris INTS; French National Center for Scientific Research, Roche, Bristol-Myers Squibb.

Universidade Positivo (UP) and Universidade Potiguar (UNP) do not offer any information on their institutional websites about partnerships with other institutions.

Also noteworthy is that there was no difference in relation to the course final assignment, which, in all cases, involves the delivery and defense of a thesis. Although it is expected for applied research to be developed in PDs rather than basic research as in an ACD, these institutions still maintain the characteristics of those first generation PDs (SEDDON, 2000 apud MAXWELL, 2003, p. 279-280), i.e., doctorates that have a series of very similar characteristics in relation to ACDs, with the defense of a thesis being the main means of obtaining an academic title, although legally there is freedom in Brazil to require other innovative formats of course completion assignments (Brasil, 2019).

Although applied research is expected to be developed in professional doctorates (PD) rather than basic research as in academic doctorates (ACDs), these institutions still maintain the characteristics of so-called first-generation DPs. It should be noted that, according to Maxwell (2003), first-generation PDs have a series of characteristics very similar to ACDs, with the defense of a thesis being the primary means to obtain the academic degree. On the other hand, second-generation DPs, as characterized by Maxwell (2003), validate products or results of the research project, different from the traditional thesis, as the form of course completion work, a fact that is not evident in the existing professional doctorates in Brazil at the time of the study.

In relation to the global reality in light of the most relevant academic rankings, mentioned at the beginning of this article, Table 1 shows the list of the 45 universities with the best performance listed according to country of origin, university, position in the academic ranking, and existence of ACDBs and/or PDBs.

Table 1: World-Class Universities that offer doctoral training in Biotechnology divided by country of origin, university, position in the academic ranking, and offerings of an Academic Doctorate in Biotechnology and/or a Professional Doctorate in Biotechnology.

Country	University	THE	QS	ARWU	ACDB	PDB
US	Harvard University	2	5	1	No	No
US	Stanford University	4	3	2	Yes	No
UK	University of Cambridge	5	3	4	Yes	No
US	Massachusetts Institute of Technology (MIT)	5	1	3	No	No
US	Princeton University	7	20	6	No	No
US	Yale University	9	14	11	No	No
US	The University of Chicago	10	10	10	No	No
US	Columbia University	11	19	8	No	No
UK	Imperial College London	12	7	23	No	Yes
Switzerland	ETH Zurich - Swiss Federal Institute	15	14	20	No	No
China	Tsinghua University	16	17	26	No	No
UK	University College London	18	9	18	No	No
US	University of Michigan-Ann Arbor	24	23	28	No	No
US	Northwestern University	24	30	30	No	No
US	University of Washington	29	-	17	No	No

UK	University of Edinburgh	30	16	-	Yes	No
China	University of Hong Kong	30	22		No	No
UK	University of Oxford	-	2	7	No	No
Japan	The University of Tokyo	-	23	24	No	No
Canada	University of Toronto	-	26	22	No	No
US	New York University	26	-	25	No	No
US	University of California, Los Angeles	20	-	13	No	No
Singapore	National University of Singapore	21	11	-	No	No
US	Cornell University	22	-	12	No	No
China	Peking University	16	18	-	No	No
US	Johns Hopkins University	13	25	-	No	No
US	University of Pennsylvania	13	13	-	No	No
US	University of California, Berkeley	8	-	5	No	No
US	California Institute of Technology	2	6	-	No	No
UK	University of Oxford	1	-	-	No	No
US	California Institute of Technology	-		9	Yes	No
France	Paris-Saclay University	-	-	16	No	No
US	University of California, San Francisco	-	-	19	No	No
US	University of California, San Diego	-	-	21	No	No
US	Washington University in St. Louis	-	-	27	No	No
US	University of North Carolina at Chapel Hill	-	-	29	No	No
US	Duke University	23	-	-	No	No
UK	London School of Economics and Political Science	27	-	-	No	No
US	Carnegie Mellon University	27	-	-	No	No
Singapore	Nanyang Technological University,	-	12	-	No	No
Switzerland	École Polytechnique Fédérale de Lausanne	-	14	-	No	Yes
US	Cornell University	-	21	-	No	No
Canada	McGill University	-	27	-	No	No
Australia	The Australian National University	-	27	-	No	No
UK	The University of Manchester	-	27	-	Yes	No

Source: Prepared by the authors in 2023.
Caption: THE (World University Rankings), QS (Quacquarelli Symonds), Academic Ranking of World Universities (ARWU).

It is observed that of the 45 universities listed as elite, there is an unequal concentration in the distribution between continents, with the majority of universities predominantly concentrated in North America with 60% (27 universities), followed by Europe with 23.44% (11 universities), Asia 13.33% (6 universities) and Oceania with 2.22% (1 university).

Another noteworthy point concerns the number of universities present in all 3 rankings: out of the 45 universities analyzed, only 14 appear in all three ranking tables. In this scenario, it is highlighted that only Stanford University and the University of Cambridge have DAC programs in

biotechnology, with Imperial College London being the sole institution offering a program in the field of DPB, focusing on Biomedical Engineering and Industrial Biotechnology.

In general, there is a small number of universities offering an ACD program focused on Biotechnology; of the 45 main universities in the world, only five offer this type of training. In relation to PDB, the number is even lower with two courses offered. Of the 45 WCUs analyzed, only Imperial College London, in the United Kingdom, and the École Polytechnique Fédérale de Lausanne, in Switzerland, offer this type of doctoral training.

Thus, as already mentioned in the research methodology carried out, given the reduced number of PDB found in the researched WCUs and in order to reach sample saturation, we expanded our search to the first 100 universities in the Academic Ranking of World Universities, ARWU - Shanghai Ranking, the only one that presents a global ranking specific for biotechnology.

As a result of this search, three new PDB were found: University of Helsinki (49th position), Finland, with the Doctoral Program in Microbiology and Biotechnology; Université Paris Sciences & Lettres (51-75th position), France, with the Biotechnology and Neuroscience program, and Universitat Autònoma de Barcelona (76-100th place), Spain, with the Doctorate in Biotechnology. It is worth noting that this classification table also includes Imperial College London (23rd position), United Kingdom, with the PhD in Industrial Biotechnology and Bioenergy, already identified in the first PDB search, and Switzerland's École Polytechnique Fédérale de Lausanne does not appear, occupying the 140th place in the QS world ranking, also identified in the first search.

Adding the results of the two searches carried out, five WCUs offering PDB were found, the same ones that served as the corpus being analyzed. In order to understand the main characteristics of these courses, in a comparative perspective, the analysis of various data was carried out, which were systematized in Charts 2 and 3, which we now delve deeper into.

Chart 2: Characteristics of World-Class Universities that offer Professional Doctorates in Biotechnology divided by country, university, course name, course objective, areas of concentration and year of creation.

Country	University	Course name	Course objective	Concentration areas	Year of Creation
UK	**Imperial College London**	Biomedical Engineering and Industrial Biotechnology	Develop or create different products to solve global challenges in food, water, and energy, improving human health and well-being.	Health, pharmaceutical production, biofuels and bioengineering.	2002
Switzerland	**École Polytechnique Fédérale de Lausanne**	Biotechnology and Bioengineering	Provide doctoral students with the education necessary to be leaders in the rapidly growing industrial and academic sectors of biotechnology and bioengineering.	Genomics and proteomics, biomolecular engineering and biomaterials, stem cell biotechnology, cell and process engineering, biochemical engineering, orthopedic engineering, biomechanics, mechanobiology, cellular biophysics, computational biology,	2005

				biomedical imaging, molecular, cellular and tissue engineering.	
Finland	**University of Helsinki**	Microbiology and Biotechnology	Develop, in addition to basic research in microbiology, research carried out in applied microbiology and biotechnology.	Food sciences, sciences (agriculture and forestry) and veterinary medicine.	2020
France	**Université Paris Sciences & Lettres**	Biotechnology and Neuroscience	Create a group of high-level young researchers with the best research and innovation skills in the biotechnology and neurosciences sector.	Neurodegenerative, demyelinating and genetic diseases.	2015
Spain	**Universitat Autònoma de Barcelona**	Biotechnology	Development of products of interest in the necessary volume from an industrial point of view.	Biotechnological engineering: microbial production of enzymes and applied biocatalysis.	2011

Source: Prepared by the authors in 2023.

Chart 2 shows that five courses offered by the main universities analyzed are located in European countries (United Kingdom, Switzerland, Finland, France and Spain).

Also noteworthy are the multidisciplinary and interdisciplinary interfaces between Biotechnology and other subject areas, as seen in chart 2; it comes to show the multiple frontiers that Biotechnology establishes with neuroscience, microbiology, bioengineering and biomedical engineering, with a strong support in the field of engineering.

We also highlight the programs offered: while Imperial College London and the École Polytechnique Fédérale de Lausanne have programs focused on biomedical engineering, industrial engineering and bioengineering, that is, programs with a strong interface with engineering, the University of Helsinki, the Université Paris Sciences & Lettres and the *Universitat Autònoma de Barcelona* focus their training in microbiology, neurosciences or just general biotechnology, respectively, with a strong concentration on biological sciences and biotechnology itself.

These data allow us to verify: a) the accentuated specialization per Institution, as different WCUs focus on different specializations in their professional doctorate programs; b) the diversity of fields of study revealed by the breadth of research and teaching in these institutions, a fact that can be attractive to different types of students and professionals who wish to improve their field-specific skills; c) regional trends of cities as technological innovation sites and areas of academic strength; d) the diverse possibilities for students within Europe, aligned with their interests and career goals; and e) the potential for interinstitutional collaboration, where researchers and students from different universities can come together to address interdisciplinary issues.

A third fact concerns course objectives, as there is an important diversification between universities. On the one hand, Imperial College London aims to develop or create different products to solve what they call global challenges in food, water, and energy, improving human health and well-being; the École Polytechnique Fédérale de Lausanne aims to provide doctoral

students with the education necessary to become leaders in the rapidly growing industrial and academic sectors of biotechnology and bioengineering; and Université Paris Sciences & Lettres aims to create a group of high-level young researchers with the best research and innovation skills in the biotechnology and neurosciences sector.

When analyzing these three PDBs, objectives beyond basic and applied research per se are noted, with speeches that highlight: a) the focus on solving global challenges, b) the training of leaders for growing sectors and c) the training of high-level investigators with the best research and innovation skills.

On the other hand, when analyzing the objectives of the PDBs of the University of Helsinki and the Universitat Autònoma de Barcelona, one can see the emphasis on basic and applied research to be carried out within the areas of specialization of each Program. In the case of the first university, the objective is to develop, in addition to basic research in microbiology, research in applied microbiology and biotechnology. In the case of the second, the objective is to develop products of interest in the volume necessary from an industrial point of view.

A fourth fact concerns the areas of concentration of the PDBs analyzed, which have applications in the most diverse fields of knowledge, such as: health, pharmaceutical production, veterinary medicine, food science, biofuels and bioengineering.

It is also observed, as a fifth fact, that all programs were recently created, all in the first two decades of the 21st century, the oldest being started in 2002 by Imperial College London followed by École Polytechnique Fédérale de Lausanne in 2005, *Universitat Autònoma de Barcelona* in 2011, Université Paris Sciences & Lettres in 2015 and University of Helsinki in 2020.

Given the data found, we also analyzed were: university, admission prerequisite, time of completion, dedication regime, financing and partnerships (Chart 3).

Chart 3: Characteristics of World-Class Universities that offer Professional Doctorates in Biotechnology: university, admission prerequisite, time of completion, dedication regime, financing and partnerships.

University	Admission prerequisite	Time of completion	Dedication regime	Financing	Partnerships	Final assignment to obtain title
Imperial College London	Candidate must have a master's degree with a final course average equal to or greater than 7.5	24 to 48 months	Full	Public - Private	UK Research Councils, industry, university scholarships and departmental funding	Thesis
École Polytechnique Fédérale de Lausanne	Candidate must have a master's degree or equivalent	48 months	Full	Public - Private	Microsoft, Microsoft Research Cambridge, Marie Curie Research Fellowship Program	Thesis
University of Helsinki	Candidate must have a master's degree, a supervisor/supervisors when	24 to 48 months	Full	Public	University scholarships and departmental funding	Thesis

	submitting the application, undergo curricular analysis and submit a research project relevant to the area					
Université Paris Sciences & Lettres	Doctoral candidates will be selected by a scientific committee made up of representatives from Biogen and PSL institutions	36 months	Partial	Private	Biogen	Thesis in addition to professional internships
Autonomous University of Barcelona	Candidate must have a master's degree or equivalent	36 months	Partial	Private	University scholarships and departmental funding	Thesis

Source: Prepared by the authors in 2023.

When analyzing Chart 3, there are important facts to be highlighted. The first of these refers to the admission criteria for the programs, which present some differences. Imperial College London, École Polytechnique Fédérale de Lausanne and the University of Helsinki require the candidate to have a Master's degree, fluency in English and the approval of a supervisor from the institution to enter the program.

In addition to this data, it is worth highlighting that specifically the Université Paris Sciences & Lettres presents, on its institutional website, very specific and innovative information, not present in the other institutions researched: doctoral candidates are selected by a scientific committee composed of representatives from Biogen, financing company and partner of the university, as well as members of the program itself.

There is also a difference in relation to the maximum time to complete the course between the universities researched. While at Imperial College London, the École Polytechnique Fédérale de Lausanne and the University of Helsinki the maximum time for completion is 48 months, this time is shorter at the Université Paris Sciences & Lettres and the *Universitat Autònoma de Barcelona*, with just 36 months for conclusion.

With regard to the dedication regime, differences are also observed between the universities investigated. On the one hand, Imperial College London, the École Polytechnique Fédérale de Lausanne and the University of Helsinki require full-time dedication to the course, a fact that a priori, in our perception, would make it difficult for doctoral students to study and work simultaneously, a reality that would go against the objectives of a PD, created to link the academic environment with an industrial reality. On the other hand, the Université Paris Sciences & Lettres and the *Universitat Autònoma de Barcelona* require partial dedication, with Université Paris going

further, having its partner Biogen within the university itself as a financier for the students, and thus enabling the students' performance in a professional environment.

For the financing regime, Imperial College London relies on resources from public and private funds with partners from UK research councils, industry, university scholarships in addition to departmental funding from the university itself. The École Polytechnique Fédérale de Lausanne has funding provided by Microsoft, Microsoft Research Cambridge, and Marie Curie research fellowships program. In the case of the University of Helsinki and Université Paris Sciences & Lettres, they are financed by a private fund, with partners being KONE Corporation, Business Finland, Academy of Finland, Metsä Group and Nokia Bell Labs in the Finnish case and Biogen in the French case. Finally, the *Universitat Autònoma de Barcelona*, in addition to private funding, also provides students with university scholarships and departmental funding from the university itself. As can be seen, the sources of financing are quite diverse, not restricted to resources from the private sector, but also involving public resources and resources from the universities themselves, depending on each case.

Regarding the assignment required for course completion, there are no differences between the Imperial College, École Polytechnique Fédérale de Lausanne, University of Helsinki and *Universitat Autònoma de Barcelona*, which follow the traditional model of completion with the presentation of a dissertation or thesis, i.e. they fall under the so-called first-generation PD (Maxwell, 2003). It is worth highlighting the model adopted by Université Paris Sciences & Lettres, which, in addition to presenting a dissertation or thesis, to complete the course also requires the student to undertake a professional internship in the area studied.

3. CONCLUSIONS

In view of the above, it can be concluded that the main trend is the reduced number of PDBs among the 45 WCUs researched, among the three main rankings analyzed, including the first 100 universities placed in the ARWU in the area of Biotechnology; only five WCUs offer this type of training in their list of courses offered. Therefore, it can be categorically stated, as a response to the main objective of this study, that PDBs are not courses commonly offered by the main universities in the world.

A second trend is the relative recent creation of PDBs in WCUs throughout the first two decades of the 21st century. The first PDB programs were only created in 2002 by Imperial College London and later in 2005 by the École Polytechnique Fédérale de Lausanne; an important contrast with the Brazilian reality is observed considering that the first PDB courses appeared only in 2019 (UNIMONTES, UNESP-BOT, UP, UNP). However, despite its later creation in relation to the European reality, in Brazil there are currently five PDB courses recognized by CAPES, a number of courses equivalent to the total number of courses identified among the main universities in the world.

A third trend is the multi and interdisciplinary character of the PDB of the WCUs analyzed, which establish frontier areas in the production of knowledge with neurosciences, biomedical engineering, microbiology and bioengineering. This fact contrasts with the Brazilian reality in which there is greater interdisciplinary dialogue with the industrial, health, agrifood, environmental and genetic resources areas.

A fourth trend identified in the PDB of the WCUs analyzed is their greater focus on the development of products and solutions in the most varied industrial areas in order to solve global

challenges, training leaders in the industrial and academic spheres, as well as young high-level researchers. Considering the Brazilian reality, the focus on training professionals for the industrial job market remains predominant, with the training of human resources aimed at the development and generation of innovative products and processes for industry, also providing the necessary improvement for the exercise of transformative and cutting-edge professional practice in an articulated and integrated way.

A fifth trend concerns the time of completion in the PDB of the WCUs studied; Imperial College London, École Polytechnique Fédérale de Lausanne and University of Helsinki define the maximum time of completion in 48 months, while Université Paris Sciences & Lettres and *Universitat Autònoma de Barcelona* maximum time of completion is reduced to 36 months. In Brazil, there is linearity between universities with a maximum time of completion of 48 months.

Finally, it is noteworthy that, with regard to the structuring of PDB programs, there is no significant difference between European programs in relation to Brazil. PDBs, in both realities, fall into what the literature calls first generation PDs, in that it requires the traditional thesis, similar to ACDs, to obtain the title.

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