

Fingerprint Research in Brazil (2020–2024): A Systematic Review of Trends, Technologies, and Institutional Collaborations

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Resumo

Este artigo apresenta uma revisão sistemática da produção científica brasileira sobre identificação por impressões digitais no período de 2020 a 2024. O objetivo é analisar a evolução temática, metodológica e institucional das pesquisas desenvolvidas no país, contextualizando-as em relação às tendências internacionais. A busca foi realizada na base Web of Science, seguindo os critérios PRISMA, e resultou na seleção de 62 estudos com afiliação institucional brasileira. Os dados foram analisados por meio de codificação temática e visualização gráfica utilizando Python. Os resultados indicam que a maior parte das pesquisas está concentrada no desenvolvimento de reagentes químicos para a visualização de impressões latentes, com destaque para materiais fluorescentes, nanopartículas e compostos sustentáveis. Embora iniciativas envolvendo inteligência artificial, espectrometria e aplicações em identificação post mortem estejam emergindo, observa-se uma limitação na validação operacional dos métodos propostos. A Universidade Federal de Pelotas, a Universidade de Brasília e a Polícia Federal lideram a produção científica nacional no tema, refletindo o fortalecimento de redes institucionais interdisciplinares. Contudo, a maioria dos estudos ainda se encontra nos estágios iniciais da pesquisa forense, conforme diretrizes do IFRG. Conclui-se que o Brasil possui uma produção científica em crescimento e alinhada às tendências globais, mas que ainda carece de investimentos em validação estatística, estudos aplicados e integração com sistemas biométricos automatizados.

Palavras-Chave: Impressões digitais; Papiloscopia; Ciência forense; Química analítica; Inteligência artificial.

Abstract

This article presents a systematic review of Brazilian scientific output on fingerprint identification between 2020 and 2024. The objective is to analyze the thematic, methodological, and institutional evolution of national research, while situating it within global scientific trends. The search was conducted through the Web of Science database, following PRISMA guidelines, and resulted in the selection of 62 studies affiliated with Brazilian institutions. Data were thematically coded and graphically analyzed using Python tools. The findings reveal a strong concentration of studies on the development of chemical reagents for latent fingerprint visualization, particularly involving fluorescent materials, nanoparticles, and environmentally friendly compounds. While research involving artificial intelligence, spectrometry, and postmortem identification is emerging, most techniques remain at early validation stages. The Federal University of Pelotas, the University of Brasília, and the Brazilian Federal Police are the leading institutions in this field, reflecting the consolidation of interdisciplinary research networks. However, the majority of Brazilian studies are still in the initial phases of forensic research, according to IFRG standards. The review concludes that Brazil has a growing and thematically aligned research landscape, but further efforts are needed in statistical validation, real-world testing, and integration with automated biometric systems.

Keywords: Fingerprints; Fingerprint analysis; Forensic science; Analytical chemistry; Artificial intelligence.

1. INTRODUCTION

Fingerprint identification is one of the most traditional and consolidated tools in forensic science, widely used in criminal investigations and civil identification processes around the world. Over the past decades, this field has undergone significant advancements, driven by the development of new physical and chemical reagents, the integration of digital imaging technologies, and the growing application of artificial intelligence in automated comparison systems [1].

According to Bécue and Champod [2], the field of fingermark analysis remains a highly active area within forensic science, with a consistent flow of research articles, case reports, and expert commentaries. In their review of the literature published between July 2019 and June 2022, the authors identified 630 relevant publications, representing a 5.2% increase compared to the previous review period, which had recorded 599 references. This growth highlights the sustained interest of the scientific community in advancing research and practice in fingerprint identification.

In Brazil, scientific interest in fingerprint analysis has intensified in recent years, reflecting the efforts of various academic and forensic institutions to promote research aimed at both technological innovation and practical application in forensic contexts [3]. However, there is a scarcity of studies that systematically consolidate the national scientific production on the subject, making it difficult to identify trends, gaps, and opportunities for strategic development.

In this sense, this systematic literature review (SLR) aims to examine the current state of research related to fingermarks in Brazil, considering the period of 2020 to 2024. The study focuses on identifying key contributions, thematic trends, methodological approaches, and existing challenges in the national scientific production on fingerprint analysis. A SLR is a form of scientific research designed to provide an unbiased and comprehensive overview of a specific topic, following a methodology that is transparent, rigorous, and reproducible [4].

2. METHODOLOGY

This study adopts a systematic literature review approach to identify and analyze scientific publications related to fingerprint identification in Brazil, published between 2020 and 2024. The purpose is to investigate how the field has evolved nationally during this period, and to contrast these findings with global scientific trends. The review follows the general principles of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure methodological transparency and replicability [5], [6].

All data processing and figure generation presented in this study were performed using the Python programming language, with the support of the following libraries: pandas, plotly.express, WordCloud, and matplotlib.pyplot. These tools enabled the processing, visualization, and graphical representation of the data extracted from the analyzed articles.

For the word cloud, a pre-processing step was performed to group semantically identical terms into their singular form, ensuring more accurate frequency analysis. For instance:

- fingerprint: {fingerprints, fingerprint}
- biometric system: {biometric system, biometric systems}
- fraud: {fraud, frauds}

This normalization allowed for clearer thematic identification and improved interpretability of the most recurrent concepts within the dataset.

2.1. Research Objectives and Questions

The primary objective of this review is to assess the evolution of scientific research in fingerprint identification in Brazil over the last five years. Secondary objectives include comparing the volume, focus areas, and institutional origins of Brazilian publications with international literature from the same period.

The guiding research questions for Brazilian publications were:

- RQ1: What are the main topics and technologies explored in Brazilian fingerprint research between 2020 and 2024?
- RQ2: What institutions are leading these studies?
- RQ3: How has the frequency and scope of publications changed over time?
- RQ4: What are the observed methodological or thematic gaps?

International publications were reviewed only for comparative purposes, and not included in the systematic analytical procedures (e.g., thematic coding or frequency quantification).

2.2. Data Sources and Search Strategy

All data were obtained exclusively from the Web of Science database, one of the most comprehensive and reputable sources of peer-reviewed scientific literature.

The search was conducted in March 2025, using combinations of the following keywords: “fingermark” OR “latent fingermark” OR “fingerprint identification” OR “latent fingerprint”.

2.3. Inclusion and Exclusion Criteria

Inclusion criteria (Brazilian articles):

- Published in peer-reviewed journals indexed in Web of Science
- Dated between 2020 and 2024
- At least one author affiliated with a Brazilian institution
- Related to fingerprint identification or biometric applications using fingerprints
- Available in full text

Exclusion criteria:

- Articles not directly related to fingerprint identification
- Editorials, letters and opinion papers
- Duplicates or publications without institutional linkage to Brazil

International articles retrieved from the same search (but without Brazilian affiliation) were used to provide a comparative overview, and were not submitted to the same in-depth analytical treatment.

2.4. Study Selection Process

The selection of articles followed four steps:

- Initial filtering of search results by title and abstract
- Application of inclusion and exclusion criteria
- Full-text reading of potentially eligible Brazilian articles
- Final selection validation

A PRISMA flow diagram will be presented in the Results section to illustrate this process.

2.5. Data Extraction and Analysis

From each selected Brazilian article, the following information was extracted and organized in a structured table:

- Title, authors, year of publication
- Institutional affiliation (Brazilian institution)
- Journal of publication
- Study type (experimental, applied, technological, theoretical)
- Main topic (e.g., latent fingerprints, DVI, spectroscopy, AI)
- Technologies used
- Area of application

Thematic coding was applied to identify dominant lines of research and to map the evolution of scientific focus during the period. Brazilian data were then compared to the broader international literature in terms of:

- Annual number of publications
- Emerging research topics
- Technological approaches and applications

3. RESULTS AND DISCUSSION

A PRISMA flowchart was developed to illustrate the selection process. A total of 8,561 articles were identified through the Web of Science database. After affiliation screening, 8,333 were excluded. From the remaining 228, title and abstract screening articles were assessed, of which 165 were excluded for not meeting the eligibility criteria. A total of 62 Brazilian studies were included in the final review. All dataset including international publications were retained for comparative analysis, although not subjected to systematic coding.

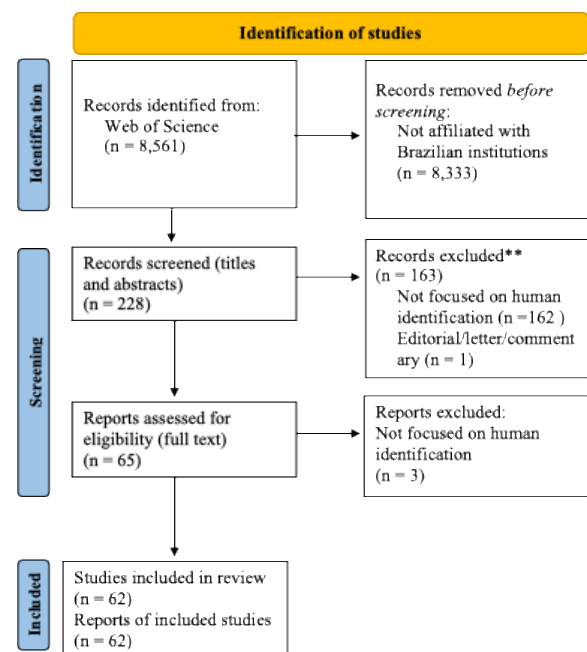


Figure 1. PRISMA flowchart.

Additional international studies used for comparison (not systematically analyzed): n = 8,333

3.1. Comparison between Brazil and the international landscape

When analyzing the global scientific production in the field of fingerprint identification between 2020 and 2024, it becomes evident that China (3,059 articles), United States (1,121 articles) and India (974 articles) are the three leading countries, followed by England (475) (Figure 1). These three countries alone account for a significant portion of the global output in this area, suggesting the existence of well-structured research ecosystems and continued investment in forensic technologies. It is important to note that the total number

of publications was assessed prior to the application of exclusion criteria (Figure 2).

In this context, Brazil ranks tenth globally, with a total of 228 publications on fingerprint identification between 2020 and 2024. This places the country ahead of several nations traditionally recognized for their scientific output in forensic sciences, such as South Korea (223), Canada (201), and Japan (188). Despite structural and financial limitations often faced by Global South countries, Brazil demonstrates a remarkable scientific engagement in this field.

When focusing specifically on the Global South, Brazil stands out as a regional and international leader. It surpasses other Latin American countries by a wide margin, Mexico (69), Argentina (32), Colombia (32), and Chile (39), as well as prominent countries in Africa and Asia, such as South Africa (83), Egypt (142), Malaysia (82), Indonesia (46), and Pakistan (94). This prominent positioning reinforces Brazil's leading role in shaping forensic fingerprint research within the Global South.

Despite its place among the top ten countries, the gap between Brazil and the global leaders remains considerable. The disparity with China, the United States, and India may be associated with differences in national research funding, technological infrastructure, and the scale of researcher engagement in the forensic sciences field.



Figure 2. Geographical distribution of scientific publications on fingerprint identification (2020–2024). The map highlights the number of publications per country, with a higher concentration observed in China, India, and the United States. Brazil ranks fourth globally, reflecting its prominent role in the Global South regarding fingerprint research.

As shown in Figure 3, the temporal analysis of scientific publications on fingerprint identification during the 2020–2024 period reveals a consistent growth trend worldwide, with the number of publications rising from 1,554 in 2020 to 1,834 in 2024. This upward trajectory reflects a sustained global interest in the field, likely driven by ongoing advances in biometric technologies, artificial intelligence applications, and the increasing need for robust forensic identification methods.

In Brazil, the number of publications fluctuated over the same period. The country registered 53 publications in 2020, followed by a slight decline in 2021 (47), a new

increase in 2022 (52), and a drop in both 2023 and 2024 (38 publications each year). Despite this recent reduction, the overall volume of national output remains significant. Compared to the previous decade (2010–2019), when 66 Brazilian publications on fingerprint identification were recorded (an average of 6.6 per year) [3], the current five-year period stands out with a total of 228 publications, surpassing the total of the entire previous decade by more than threefold and in half the time. This growth suggests a consolidation of Brazil's research capacity in the area, likely influenced by academic collaborations and institutional support from public forensic bodies.

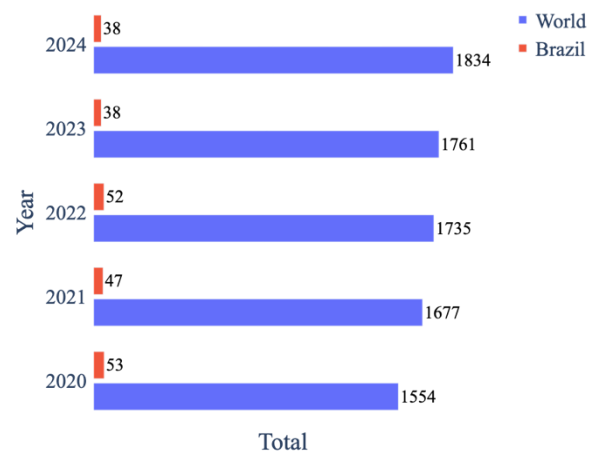


Figure 3. Annual distribution of scientific publications on fingerprint identification from 2020 to 2024. The figure compares the total number of articles published worldwide (in blue) with those authored by Brazilian institutions (in red).

Table 1 shows the institutions with the highest number of scientific publications on fingerprint identification during the 2020–2024 period, based on the affiliations of the corresponding authors. The data reveal a clear dominance by institutions from China and India. The Chinese Academy of Sciences leads the ranking with 348 publications, followed by the Centre National de la Recherche Scientifique (CNRS, France) and the University of Chinese Academy of Sciences, both with 146 publications each. Other prominent institutions include the Egyptian Knowledge Bank (134), Indian Institute of Technology System (102), and University of California System (102), highlighting the international and multidisciplinary nature of research in this field.

Several Chinese universities also feature prominently, such as Southeast University (96), Zhejiang University (88), and Tsinghua University (82), reinforcing China's central role in global forensic research. Indian institutions such as Tumkur University (96) and Jain University (72) also demonstrate significant contributions, while European and American institutions such as the Helmholtz Association (70), State University System of

Florida (63), and University of London (62) remain consistently active.

Regarding Brazilian representation, the Universidade de São Paulo (USP) appears with 30 publications, placing it among the top 100 institutions globally in this field. Additionally, the Universidade de Lisboa, often collaborating with Brazilian researchers, also recorded 30 publications. These numbers indicate a growing presence of Lusophone institutions in international forensic research, although the overall participation of Brazilian institutions remains limited compared to Asian and European counterparts.

Table 1. Top 10 institutions with the highest number of scientific publications on fingerprint identification between 2020 and 2024.

Affiliation	Total Publications
Chinese Academy of Sciences	348
Centre National De La Recherche Scientifique Cnrs	146
University Of Chinese Academy Of Sciences Cas	146
Egyptian Knowledge Bank Ekb	134
Indian Institute Of Technology System Iit System	102
University Of California System	102
Southeast University China	96
Tumkur University	96
Zhejiang University	88
Tsinghua University	82

The classification of fingerprint identification publications by research area (Figure 4), based on Web of Science indexing, reveals a strong concentration in Chemistry, which accounts for 2,310 global publications and 75 Brazilian ones. This is followed by Engineering (1,577 global / 16 Brazilian), Computer Science (1,573 / 17), Biochemistry and Molecular Biology (755 / 22), and Legal Medicine (304 / 18). These domains emphasize the interdisciplinary nature of fingerprint research, combining chemical, biological, and computational approaches for fingerprint visualization, enhancement, and interpretation.

Other relevant fields include Food Science and Technology (556 / 18), Environmental Sciences and Ecology (395 / 16), and Pharmacology and Pharmacy (418 / 12), indicating the growing interest in chemical substrates, toxicological applications, and trace analysis within fingerprint residues. The presence of Materials Science (712 / 12), Spectroscopy (290 / 12), and Plant Sciences (324 / 12) further reflects the experimental focus on the development of novel detection reagents and substrate interactions.

Although Brazil contributes a smaller absolute number of publications across these fields, its thematic alignment with global trends is clear. The strong national presence in Chemistry, Biochemistry, and Legal Medicine suggests that Brazilian research remains rooted in traditional pillars

of forensic science, while also expanding into emerging areas such as Computer Science, Environmental Sciences, and Food Technology.

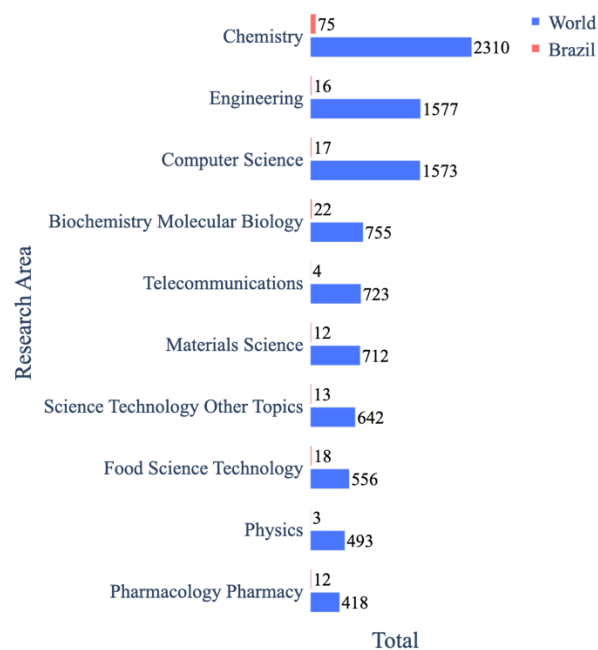


Figure 4. Distribution of fingerprint identification publications by research area, according to Web of Science classification (2020–2024). Chemistry, Materials Science, and Legal Medicine are the most represented fields globally and in Brazil, reflecting the multidisciplinary nature of fingerprint research.

The analysis of document types indexed in the Web of Science between 2020 and 2024 shows that the vast majority of global publications on fingerprint identification are classified as original research articles ($n = 7,235$), followed by proceedings papers ($n = 836$) and review articles ($n = 468$). Brazil follows a similar pattern, with 194 articles, 15 proceedings papers, and 18 review articles, indicating that the country's scientific contribution is also centered on peer-reviewed journal publications, as showed on Figure 5.

Other document types appear much less frequently. In the global dataset from Web of Science, there are 93 early access publications, 30 book chapters, 17 meeting abstracts, 13 editorials, and smaller numbers of corrections, retracted publications, data papers, letters, and retractions. In Brazil, the representation of such types is minimal or nonexistent. The country registered only 6 early access publications, 1 meeting abstract, and 1 letter. No Brazilian publications were categorized as book chapters, editorials, corrections, retractions, or data papers in this dataset.

It is important to emphasize that this distribution reflects only the data retrieved from the Web of Science database. Within this scope, it reinforces the central role of original articles as the primary vehicle for disseminating

fingerprint identification research, both globally and in the Brazilian context. The relatively small number of non-article documents also suggests a focus on consolidated research findings rather than preliminary communications or editorial content.

Article	Correction	Early Access	Letter	Proceeding	Retracted
World 7235	World 10	World 93	World 3	World 836	World 9
Brazil 194	Brazil 0	Brazil 6	Brazil 1	Brazil 15	Brazil 0
Book Chap	Data Paper	Editorial	Meeting	Retraction	Review
World 30	World 7	World 13	World 17	World 2	World 468
Brazil 0	Brazil 0	Brazil 0	Brazil 1	Brazil 0	Brazil 18

Figure 5. Distribution of document types on fingerprint identification indexed in the Web of Science (2020–2024). The majority of publications are original research articles, both globally and in Brazil. Other formats, such as reviews and conference papers, appear in smaller proportions.

Figure 6 shows the word cloud generated from the keywords of the analyzed articles highlights the predominant concepts and thematic concentrations in fingerprint identification research between 2020 and 2024. The most prominent expressions include “latent fingerprint”, “fingerprint”, “fingerprint”, and “forensic science”, indicating the centrality of forensic applications and the persistent focus on developing and enhancing latent print visualization techniques.

Additionally, the presence of expressions such as “deep learning”, “machine learning”, “feature extraction”, “convolutional neural network”, and “photoluminescence” illustrates the growing integration of artificial intelligence and advanced imaging techniques in the field. Terms like “chemometric”, “nanoparticle”, and “mass spectrometry” further reflect the interdisciplinary nature of modern fingerprint research, particularly the convergence of forensic science, biotechnology, and materials science.

By grouping variations of similar expressions (e.g., “latent fingerprints” and “latent fingerprint”) and normalizing them into singular form, the word cloud enhances the accuracy of frequency representation. This visualization clearly reveals the prevailing research directions, emphasizing the impact of AI-driven methodologies and the exploration of novel chemical and optical approaches for fingerprint detection and recognition.

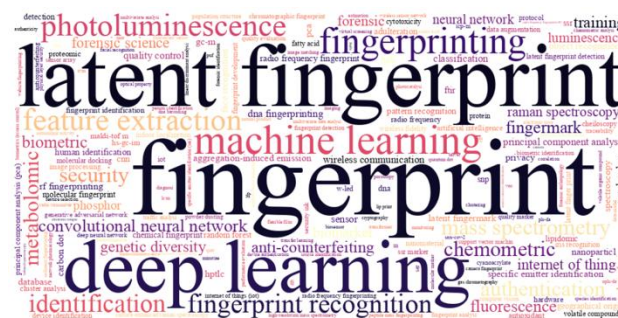


Figure 6. Word cloud based on keywords extracted from fingerprint identification articles (2020–2024). Related terms were grouped and normalized to singular form to ensure semantic accuracy. The most frequent terms reveal thematic emphases on latent fingerprint detection, forensic applications, and the integration of photonic, chemical, and machine learning technologies.

3.2. Reflections on the evolution of the field

In this section, we present the discrete and continuous quantitative data extracted from the 62 primary studies that support formulating the answers corresponding to the four secondary questions of the research. It is important to note that, for the discussions presented here, the affiliation of all authors was considered, rather than only the corresponding authors, as was done in the comparison between Brazil and the rest of the world. This approach was feasible due to the smaller number of articles evaluated at this stage, allowing for a more detailed analysis.

3.3.1. RQ1: What are the main topics and technologies explored in Brazilian fingerprint research between 2020 and 2024?

Between 2020 and 2024, fingerprint research in Brazil was predominantly centered on the development of latent fingerprint visualization techniques, especially through the creation and testing of novel chemical reagents and materials. A total of 28 studies [7-34] focused on the formulation and application of nanomaterials, including quantum dots, fluorescent polymers, and green-synthesized particles, for enhancing ridge detail on porous and non-porous surfaces. These works emphasized aspects such as green chemistry, sensitivity, adherence to forensic protocols, and dual-functionality material.

Artificial intelligence and computational methods emerged as growing themes in more recent studies. Article [35] proposed a convolutional neural network (CNN)-based model for automatically selecting the best enhancement technique for latent fingerprints. Articles [36] and [37] applied deep learning models (including residual M-Net and CNNs) for minutiae extraction and segmentation, contributing to automation in image preprocessing. Article [38] introduced a self-supervised Siamese network with contrastive learning, allowing

fingerprint matching without reliance on proprietary datasets.

Emerging biometric approaches also expanded the diversity of recognition strategies. Article [39] demonstrated the practical potential of smartphones for latent fingerprint capture and visualization in forensic settings, offering a low-cost and portable solution. Article [40] presented a case study applying machine learning to identify sensor “fingerprints” in dam monitoring systems, highlighting its relevance to cybersecurity. Meanwhile, [41] explored handwritten dynamics via CNNs as a form of digital biometric identification, and [42] introduced plantar pressure as a biometric trait, using support vector machines for classification. Article [43] tackled computational limitations by leveraging cloud and edge computing to accelerate fingerprint recognition on mobile devices, promoting scalability and real-time performance in biometric systems.

The chemical characterization of fingerprints continued to be a promising frontier in forensic science, offering insights beyond biometric identification. Studies such as [44], [45], and [46] applied mass spectrometry and chromatography techniques to explore the endogenous and exogenous compounds present in fingermarks, enabling molecular-level analyses with potential for personal identification, drug adherence monitoring, and the detection of environmental exposure. Particularly, [44] innovatively employed greenly synthesized silver nanoparticles for SALDI-MS analysis, while [45] assessed the impact of lipid degradation in fired cartridges, and [46] explored the viability of carbamazepine detection in patient fingerprints.

Complementarily, [47] and [48] expanded the scope of chemical analysis by applying advanced mass spectrometry imaging techniques. [47] used MALDI-MSI to monitor chemical degradation in fingerprints and demonstrated the feasibility of ridge visualization for up to 50 days. [48] applied paper spray ionization mass spectrometry (PS-MS) to detect fatty acids and compare the effectiveness of novel curcumin-based fingerprint developers, contributing to both chemical profiling and visualization of minutiae.

Additionally, efforts to estimate the age or sex of fingerprint donors advanced the evidentiary potential of these traces. [49], [50], and [51] investigated fingerprint aging using FTIR microscopy, GC-FID, and near-infrared hyperspectral imaging, respectively, highlighting the potential to determine the time since deposition through chemometric and spectral analyses. Meanwhile, studies such as [52], [53], and [54] demonstrated the use of vibrational spectroscopy and morphological features for sex determination, with high discrimination accuracy, reinforcing the role of fingerprints as a source of rich forensic intelligence.

Postmortem fingerprint identification was also addressed through innovative procedures. [55] illustrated the practical role of friction ridge analysis in disaster victim identification (DVI), including the use of automated systems in major Brazilian cases. [56] proposed an enhancement to the transillumination technique by incorporating moistened black volcano powder, significantly improving fingerprint recovery from fragile, postmortem skin.

Moreover, 12 articles were classified as literature reviews [57-68]. These works address advances in fingerprint analysis within forensic science, focusing on analytical techniques for identifying chemical and biological components present in the residues.

Al together, the 62 analyzed articles reflect a vibrant and multidisciplinary research landscape in Brazil. The integration of chemistry, material science, computational intelligence, and forensic application demonstrates a mature fingerprint research field. The studies not only seek to enhance technical procedures but also show commitment to expanding the analytical potential of fingerprints, thus aligning Brazil's scientific output with global forensic trends.

3.3.2. RQ2: What institutions are leading these studies?

During the analyzed period (2020–2024), fingerprint research in Brazil was characterized by robust interinstitutional and interdisciplinary collaboration, with a few institutions emerging as consistent leaders.

The Federal University of Pelotas (UFPe) stands out as the most prominent academic institution, appearing in 28 studies. Many of these involved partnerships with the Brazilian Federal Police and other universities such as USP, UFRGS, and UFES. This confirms UFPe's central role in developing novel fingermark detection materials and in fostering collaborative research networks.

The University of Brasilia (UnB) is the second most frequently affiliated institution, appearing in 17 studies, often in close collaboration with the Federal Police. UnB's contributions are especially relevant in projects involving chemical characterization, spectroscopy, and nanotechnology applied to operational forensic practice.

The Federal University of Rio Grande do Sul (UFRGS) appears in 9 studies, reinforcing the institution's leadership in Southern Brazil and its commitment to forensic science through chemical and material-based fingerprint research.

The Federal University of Alagoas (UFAL) appears in 7 studies, frequently in collaboration with the Instituto Federal de Alagoas (IFAL) and international partners such as the University of Leicester. Their research focuses on electrochemical sensing, biomaterials, and imaging technologies.

The Brazilian Federal Police (Polícia Federal) is listed as an institutional affiliation in at least 27 studies, reaffirming its role not only as a user of forensic science but also as an active producer of knowledge. Its collaborations cover diverse topics (from the operational application of forensic methods to the development of new revealing agents) and connect with nearly all major academic institutions in the country. An important contextual factor in this growth is the establishment, in 2020, of the Forensic Fingerprint Research Group (Papiloscopia Forense) at the Brazilian Federal Police Academy (Academia Nacional de Polícia) and the National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq). The impact of this initiative is clear: while from 2010 to 2019 the Federal Police was involved in only 7 fingerprint-related publications [3], from 2020 onward it participated in 27 studies (300% increase). Notably, 22 out of these 27 studies (81.4%) included members of the Forensic Fingerprint Research Group. When considering that a total of 62 Brazilian articles were included in this review, it becomes evident that the group directly contributed to over 35% of the national fingerprint-related scientific output.

This sharp increase reflects not only institutional commitment to scientific development but also a strategic effort to position the Federal Police as a key actor in the national forensic research landscape. This updated mapping reveals that fingerprint research in Brazil is sustained by a distributed network of institutions, rather than a single academic pole. These networks are largely anchored by federal universities, research institutes, and the Federal Police, and their collaborative nature has been crucial for expanding the scientific and practical relevance of the field.

3.3.3. RQ3: How has the frequency and scope of publications changed over time?

Between 2020 and 2024, the frequency and thematic scope of fingerprint-related publications in Brazil showed a clear trend of diversification and interdisciplinary expansion. In 2020 and 2021, the number of publications remained stable, with ten studies published in each year. These early contributions were primarily concentrated on the development of latent fingerprint reagents and review articles, reflecting an initial phase of material exploration and methodological consolidation.

In 2022, publication frequency increased to 14 articles, coinciding with the emergence of new research areas. In addition to continued material development, this period marked the first studies involving sex estimation, chemical characterization through chromatography and vibrational spectroscopy, and initial applications of

artificial intelligence. This expansion of topics indicated an increasing interest in analytical and evidentiary potential beyond biometric matching.

The year 2023 saw a slight decrease to 11 publications but maintained a high level of thematic diversity, including the first postmortem studies and further development of AI-based techniques. By 2024, the volume rose again to 17 studies, reaching the highest annual number in the period analyzed. These contributions reflected a strong presence of advanced technologies such as machine learning, deep neural networks, and spectroscopic imaging (e.g., MALDI-MSI, FTIR, NIR), as well as interdisciplinary applications, including DVI operations, mobile-based identification, and sex/age estimation.

Over the five-year period, the frequency of publications remained relatively stable, but the scope of research expanded significantly, evolving from core fingerprint development to broader forensic applications and technological integration. This trend indicates a maturing scientific field aligned with global forensic innovation fronts.

Additional metrics reinforce this picture of progressive scientific development. Funding information was explicitly declared in approximately one-third of the studies, with the most frequent sponsors being public research agencies such as CAPES (10 mentions), CNPq (6), and FAPESP (4). Although the Brazilian Federal Police was a frequent institutional co-author, it appeared as a funding source in only two articles, highlighting a potential institutional gap in research investment.

From a visibility standpoint, no Brazilian fingerprint publications received the “Hot Paper” or “Highly Cited” designations by the Web of Science Core Collection. Nevertheless, several studies achieved considerable citation impact, with references [62], [60], and [57] receiving 28, 24, and 22 citations respectively, suggesting growing international recognition.

Regarding dissemination, 27% of the studies were published in open access formats, with the majority following the gold access model. This contributes to the broader accessibility of forensic research and aligns with global trends in science communication. Furthermore, although relatively infrequent, a subset of Brazilian studies was presented at major international conferences, such as IEEE WCCI, SIBGRAPI, and SBQT, underscoring the increasing participation of national researchers in global academic and forensic science communities.

3.3.4. RQ4: What are the observed methodological or thematic gaps?

Despite notable advances in Brazilian fingerprint research between 2020 and 2024, several methodological

and thematic gaps were identified. One of the most striking observations is the overrepresentation of studies focused on the development of revealing agents—with 28 out of 62 articles (45%) dedicated to this topic. While innovation in reagents is fundamental, this thematic concentration suggests a relative lack of diversification in experimental objectives.

A clear methodological gap is the limited use of standardized validation protocols, particularly in studies that propose new materials or visualization techniques. Many of these works focus on laboratory performance under controlled conditions but lack field testing, blind comparisons, or statistical validation involving real casework, which are essential for forensic admissibility and operational implementation. It is essential for Brazil to advance to more mature stages of fingerprint research. According to the Guidelines for the Assessment of Fingerprint Detection Techniques published by the International Fingerprint Research Group (IFRG), there are four distinct phases of development in fingerprint research. Currently, most studies conducted in Brazil remain at Phase 1—which includes pilot studies and proof-of-concept experiments—or, at best, Phase 2, involving controlled laboratory validations. To strengthen scientific credibility and operational applicability, future research should aim to progress toward Phase 3 (operational trials) and Phase 4 (routine implementation and impact assessment) [69].

Additionally, areas such as automated fingerprint comparison systems, quality assessment metrics, and integration with national or international AFIS systems are scarcely represented. Only a small number of studies [35, 36, 37, 41] explored machine learning or deep learning applications for pattern recognition, indicating a need for greater investment in AI-driven biometric matching and automation.

Thematically, some relevant applications remain underexplored, such as children's fingerprints, persistence studies in tropical climates, influence of substrate variability, and integration with other forensic modalities (e.g., facial recognition, DNA trace co-localization). There is also a notable gap in studies focused on error rates, examiner bias, and human factors, which are critical topics in international forensic discourse but are still emerging in the Brazilian context.

3.3. Implications for Forensic Practice and Professional Training in Brazil

The analysis of Brazilian scientific production on fingerprint research between 2020 and 2024 reveals important implications for the advancement of forensic practice and the professional training of individuals working in the field. The strong concentration of studies focused on latent fingerprint development using new materials demonstrates a commitment to technical

innovation and the search for more efficient and sustainable solutions for trace processing. However, it also highlights the need to validate these techniques in real-world scenarios, ensuring their applicability across diverse forensic environments.

The significant presence of the Federal Police as a collaborating institution in several studies signals a promising rapprochement between science and practice, creating opportunities for academic knowledge to be integrated into the day-to-day procedures of criminal investigations. This collaboration—especially with universities such as UnB and UFPel—reinforces the importance of institutional policies that promote integration between research laboratories and forensic services, encouraging joint projects, operational testing, and mutual professional development.

On the other hand, the identified thematic and methodological gaps, such as the limited number of studies on comparison quality, AI-based automation, statistical validation, and human error analysis, highlight critical issues that must be addressed to align Brazilian forensic practice with international standards of reliability and transparency. These gaps should inform not only the direction of future research but also the curricular revision training programs and ongoing professional development for fingerprint experts, forensic analysts, and other criminal justice professionals.

Additionally, emerging topics such as fingerprint aging estimation, sex determination through chemical residues, and applications in disaster victim identification (DVI) indicate an expanding field in which fingerprint analysis transcends its traditional role and begins to intersect with areas such as analytical chemistry, forensic anthropology, and data science. This demands a multidisciplinary training approach, emphasizing scientific methodology, critical analysis, emerging technologies, and awareness of the ethical and legal dimensions of forensic work.

The findings of this review suggest that, although Brazilian fingerprint research has advanced considerably, it must now be strategically directed to reinforce its practical application, technical robustness, and educational role within the context of public security and the criminal justice system.

Most Brazilian fingerprint research was funded by national public agencies, notably the CNPq and CAPES, followed by state-level foundations such as FAPESP and FAPESP. This reliance on governmental support highlights the strategic role of public science policy but also reveals a low diversity of funding sources, with limited participation from private or international initiatives, even in areas with high potential for technological application and forensic innovation.

4. CONCLUSIONS

This systematic review examined fingerprint-related scientific publications in Brazil between 2020 and 2024, analyzing their frequency, institutional affiliations, thematic trends, technologies explored, and research maturity. The results indicate that although the annual number of publications remained relatively stable, there was a significant expansion in thematic scope, methodological complexity, and interdisciplinary approaches.

The field remains strongly centered on latent fingerprint development, particularly through the use of nanomaterials, conductive polymers, and fluorescent compounds. However, recent years have shown a notable shift toward advanced technologies, including machine learning, deep neural networks, vibrational spectroscopy, and mass spectrometry imaging. These tools have enabled research not only in fingerprint enhancement, but also in donor profiling, chemical characterization, postmortem identification, and mobile biometrics.

Institutionally, the scientific landscape is dominated by a few leading universities, most notably UFPel, UnB, and UFRGS, and consistently involves the Brazilian Federal Police as both research partner and data provider. The creation of the Forensic Fingerprint Research Group in 2020 was a key turning point that catalyzed much of the scientific output in this period, contributing to over 35% of the national production.

Despite these advances, the analysis revealed important gaps. Most Brazilian studies remain in early research phases (pilot or proof-of-concept), with limited efforts reaching validation or operational deployment, as described by the IFRG's international guidelines for fingerprint technology assessment. Additionally, few studies reported external funding, and even fewer achieved high citation impact or were presented in international venues—suggesting the need for stronger research dissemination strategies and more robust funding mechanisms.

In sum, fingerprint research in Brazil is experiencing a moment of growth, diversification, and increasing technical sophistication. Continued investment in applied studies, international collaboration, and research evaluation frameworks will be essential to consolidate Brazil's position in the global forensic science landscape and ensure the translation of innovation into operational impact.

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