



# Forensic entomology in research and practice: an overview of forensic experts' perceptions and scientific output in Brazil

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## Abstract

Given the growing demands for standardization of procedures for collection, preservation, and identification of insect specimens, this study aimed to identify how forensic entomology is used in Brazil and the perceptions of professionals involved in this process. We conducted: (1) bibliometric survey of the scientific production of forensic specialists from 2001 to 2020; (2) questionnaire applied to forensic professionals to verify their perceptions about the use of entomological evidence in practice. An increase in publications on Forensic Entomology was noticed in the last 5 years, mainly in the South and Northeast regions. Of the 82 respondents to the questionnaire, 62.8% deal with cadavers at least once a week, but 89.0% of the professionals who examine cadavers weekly find less than 10.0% colonized by insect larvae. Using entomological evidence to estimate PMI was mentioned by only 36.6% of the professionals. Most respondents stated no procedures related to collecting, handling, or identifying necrophagous insects in their daily practice. Regarding the chain of custody, 64.6% said they were aware of the changes in the regulations involving the collection and maintenance of forensic evidence. We emphasize the importance of collaboration between scientists at universities and crime scene examiners. Although the use of entomological evidence in criminal investigations in Brazil is still scarce, a growing interest in this area can be detected among forensic experts.

**Keywords** Chain of custody · Legal medicine · Forensic science · Post-mortem interval · Entomological evidence

## Introduction

### Crime and investigation in Brazil

Few countries would be as suited to strengthening Forensic Entomology (FE) as Brazil. A combination of factors, such as the mega-diversity of necrophagous insects, the variety of landscapes, the excellence of scientific education in Entomology, and the training of police staff tragically coexist

with soaring homicide rates [1]. It is not by chance that 11 of the 50 most violent cities globally — among cities with over 200,000 inhabitants — are located in Brazil [2].

Forty-four thousand lives were taken violently in 2020 in Brazil. However, violence is not evenly distributed in the 27 states — grouped into five regions: North, Northeast, Southeast, South, and Midwest. Homicide rates are higher in more populous cities located in regions with lower human development indices, such as the Northeast and North regions of the country (Fig. 1). The violence inequality is aggravated by the concentration of more consolidated police forces and forensic research centers in Southeastern states and the capital, Brasília.

Homicide investigation in Brazil is the responsibility of police professionals at the state level, who work in the most diverse areas, such as crime scene expertise, legal medicine, ballistics, legal dentistry, computer sciences, engineering, finance, accounting, chemistry, electronics, environmental sciences, genetics, traffic accidents, and even explosives. Joining the police force in Brazil is a highly competitive

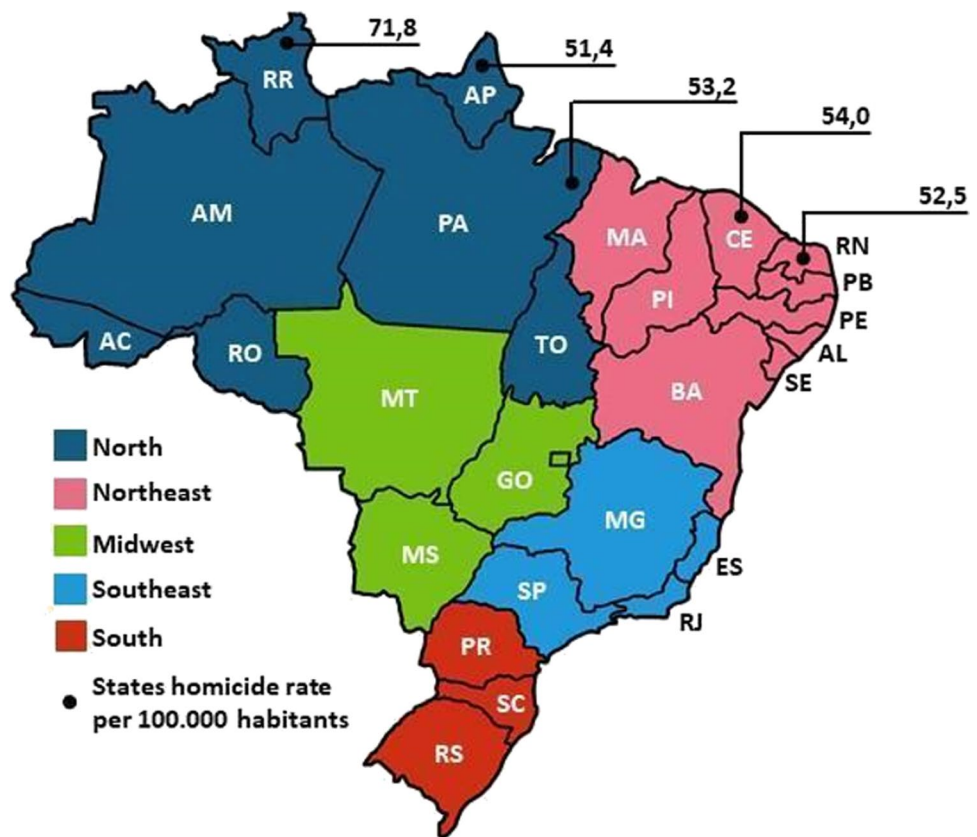
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**Fig. 1** An overview of homicide rates (per 100,000 inhabitants) in the five regions of Brazil, highlighting the most violent states (Data from IPEA, 2020 [3])



process, through a federal or state public examination, and it is followed by a long, scientific, and physical comprehensive training, which tends to select highly skilled professionals.

Cadavers resulting from homicides are taken to the Institute of Legal Medicine (ILM), which has unequal levels of infrastructure and personnel among the different states. At the ILM, forensic experts examine the corpses, estimate the post-mortem interval (PMI) and determine the cause of death. The police will then use the report written by forensic experts to help in the elucidation of crimes.

The use of entomological evidence is not stipulated in the Brazilian legislation. However, it is expected that such guidelines follow the guidelines for biological evidence, with the necessary care to ensure the suitability of the evidence [4]. Until recently, no official legislation defined the procedures that should be taken by the police at crime scenes, and investigators had only four articles in the Code of Criminal Procedure describing the need for crime scene preservation and evidence storage for future consultation. However, a recent change in the Brazilian legislation (Law 13.964/2019) turned the collection, cataloging, and storage of forensic evidence part of the responsibilities of criminal experts [5].

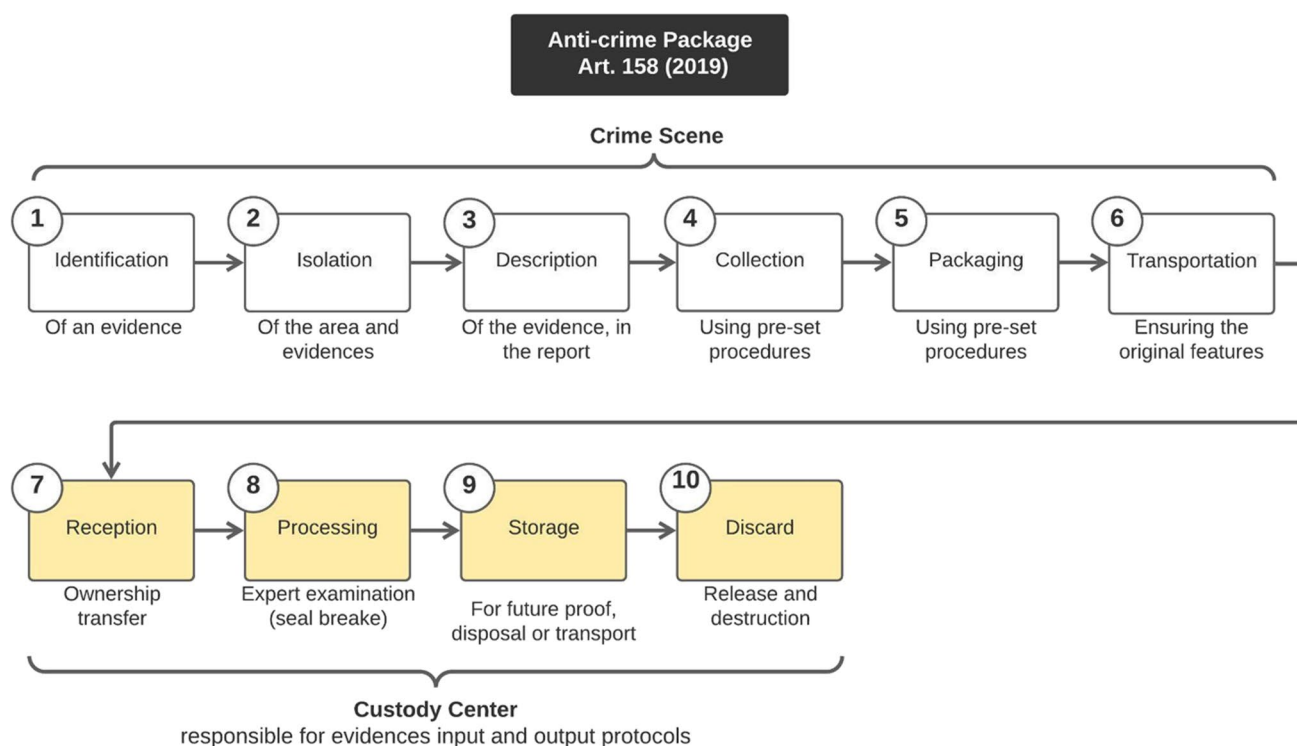
With the new legislation, the steps and procedures of the chain of custody were defined. Additionally, central offices were installed for controlling the receipt and discard of

evidence, aiming to ensure the suitability of the expert evidence, establishing a crime chronology [6] (Fig. 2). Article 158 in the new law states that the “Chain of custody is the set of all procedures used to maintain and document the chronological history of the trace collected in sites or victims of crime, to track their possession and handling from their recognition until disposal” [5]. The extent to which the changes in the legislation were discussed by (and had the input of) forensic experts is uncertain.

According to Amendt et al. [7], the standards for forensic entomology methods are currently not legislated in any country, but internationally accepted technical standards (general requirements, education, professional experience, examinations, assessment, renewal of certification, and revocation) are pursued in several countries — such as the American Board of Forensic Entomology (ABFE) in the USA. Unfortunately, the debate is still embryonic in most countries.

### Opportunities for forensic entomology

Brazil has a long history in Forensic Entomology since the seminal works of Oscar Freire and Roquete Pinto in the first decade of the twentieth century [8]. In the late 1990s, a renewed interest in forensic entomology fueled the consolidation of research centers in the University of Brasília, in the



**Fig. 2** Flowchart with steps of the chain of custody according to the Anti-Crime Package

central-west region of the country, and in the states of Rio de Janeiro and São Paulo. Since then, the Federal Government's Ministry of Justice has promoted courses and training to hundreds of criminal experts from all country regions.

At the same time, there has been a growing specialization of criminal experts in Masters and Doctorate courses in the country. New research groups in forensic entomology in Brazilian universities have been created since 2005. A natural consequence of this training would be the increase in the frequency of entomological evidence in criminal investigations and, from an academic point of view, a rise in the publication of scientific articles on forensic entomology written by criminal experts. The innovative research on forensic entomology in Brazil has been evidenced in a recent bibliometric review on Forensic Entomology articles published in indexed journals in the last 20 years: Brazil represents 13.8% of the total number of articles, ranking second in the world, behind only the USA [9].

The involvement of forensic experts as authors of articles in forensic entomology is a reliable indicator of their involvement in scientific research. A critical step for validating such studies is their publication in peer-reviewed journals so that experts in the field can review, question, and check the repeatability of the results [10]. Sharing successful experiences in specialized journals requires compliance to standardized protocols regulated by the chain of custody in the case of homicide investigation.

Magni et al. [11] performed a survey on the status of forensic entomologists in the world, in which the workload, job involvement, scientific output, and experiences in cases in the scene of crimes are discussed. Unfortunately, no Brazilian scientists were represented in the study, even though our survey on the database of academic researchers in Brazil reveals that at least 340 scientists with a Ph.D. include “forensic entomology” as a keyword in their fields of investigation.

The experience of academic researchers has been the focus of recent studies in forensic sciences (e.g. Górka and Plens [12]), but little attention has been devoted to the practice of forensic entomologists who work for the police. Some incongruity in the protocols of casework reports (e.g., accreditation) devised by police forces in different countries — and even between different states in a country was detected in a survey among forensic entomologists [11]. The gap between academic research and police procedure appears to be a common trait in many countries.

Amendt et al. [13] point out that local academic studies are needed for a worldwide standard procedure in Entomology to be used in forensic investigations. Following those guidelines, Thyssen et al. [14] helped the police investigate a homicide in Southern Brazil by providing reliable evidence based on entomological data. However, a central issue in developing forensic entomology in Brazil involves the lack of financing, insufficient state investment, and unequal

resource distribution. Institutes of Legal Medicine operate at the state level. As a result, some states offer relatively efficient support, while others are greatly unsatisfactory [12].

## Objectives and scopes of the study

Given the increasing need for standardization of procedures of collection, preservation, and identification of insect specimens [13], we share the concern expressed by Magni et al. [11] on the necessity to identify not only *how* forensic entomology is carried out, but also *who* is involved in the process, their perceptions and expectations. Global insights on the practice of forensic entomology can help detect gaps that could be overcome by scientific research and strengthen repeatable, reliable protocols used by police — especially in countries devastated by high rates of homicide.

In this study, we were motivated to investigate the involvement of forensic experts in scientific research on forensic entomology and the practical use of entomological evidence in the examination of cadavers taken to Institutes of Legal Medicine. Specifically, we aimed to (i) investigate the perceptions of criminal experts about the importance of entomological evidence in their professional practice; (ii) detect previous experiences and interests of FE experts, as well as possible obstacles to its use; and (iii) analyze the involvement of criminal experts in the production of scientific knowledge disseminated in indexed journals.

## Methods

The target public of this research consisted of forensic experts, medical examiners, and necropsy technicians (hence referred to as forensic experts) from the five regions of Brazil because they are directly involved with the steps of the chain of custody, from the collection of evidence to the determination of its forensic value.

### Bibliometric survey of forensic experts' scientific output

In order to describe the forensic experts' academic production in Forensic Entomology, we performed a thorough bibliographical survey of papers published in indexed scientific journals, with ISSN, editorial board, and peer review from 2001 to 2020. We searched on databases from Web of Science®, PubMed, Google Scholar, Scopus, *Periodicos Capes* (a Brazilian catalog that provides access to articles from over 15,000 scientific journals and 130 databases) and the Scientific Electronic Library Online (SciELO), a database that covers Latin American scientific journals. Additionally, we searched for scientists who work on forensic entomology by browsing the *Curriculo Lattes* database, maintained by the

Brazilian Ministry of Science and Technology, which comprises virtually all personnel involved in scientific research in the country.

We used the following keywords, isolated or in groups, using boolean operators (“AND”/“OR”), in English, Portuguese and Spanish: “Diptera”, “Coleoptera”, “Calliphoridae”, “Sarcophagidae”, “Muscidae”, “Fanniidae”, “Phoridae”, “Cleridae”, “Dermestidae” (and scientific names of species), “forensic entomology”, “maggots”, “sarcosaprophagous insects”, “necrophagous insects”, “cadaver”, “corpse”, “carion” “post-mortem interval”, “legal medicine” and “Brazil”. We used terms like “police institute”, “criminalistics” and “forensic police” (alone or in combination) as filters.

We selected all articles of which at least one author works for the forensic police. To outline the temporal and geographic distribution of scientific production in the country, we used two variables: the region of Brazil (five regions) and the year of publication, organized into four quinquennia, from 2001–2005, 2006–2010, 2011–2015 to 2016–2020.

### Perceptions of forensic experts about the use of entomological evidence in their professional practice

To characterize the forensic experts' previous experience, perceptions, and opinions on forensic entomology and chain of custody, we applied an online questionnaire using Google Forms. The 20-question form was accompanied by a letter of introduction outlining the purpose of the survey. We had access to mailing lists and social networks of forensic experts. We sent 120 questionnaires to professionals from all regions and got 82 responses. Responses were anonymous and had the authorization of the respondents for use in scientific research.

The questionnaire was structured around three topics: (i) professional training and handling of cadavers colonized by insects; (ii) applicability and interest in Forensic Entomology; and (iii) perception on the chain of custody related to biological evidence.

We sought to characterize the frequency of contact of the professionals with the FE, their training/interest in the area, and their knowledge of the new legislation, perceptions, and opinions of the respondents. The answers were ranked based on a Likert scale, composed of five options, of which “1” meant total disagreement, “3” a neutral central option for cases of indecision or neutrality, and “5” a total agreement.

Finally, using open-ended questions, we surveyed the professionals' opinions about the new chain of custody legislation and the negative and positive points regarding the inclusion of entomological evidence in this procedure.

Numerical data were compared using a Chi-Square test. The open-ended questions were categorized qualitatively. The graphs were generated in Google Forms and Excel. *P*

and  $\chi^2$  values were obtained by PAST software, version 4.03, with level significance  $\alpha = 0.05$ .

## Results

### Scientific output of forensic experts on forensic entomology

We retrieved 58 scientific articles on Forensic Entomology whose authorship includes at least a forensic expert in the police force. There was a marked increase in the number of publications over the years, especially in the last quinquennium, which totaled almost ten times more articles than that observed in the 2001–2005 period. Despite a high number of articles published by experts based in the Southeast Region (36.2%), there was an increasing equalization of publications in the last 5 years throughout the Brazilian regions (Fig. 3). To illustrate that, the South and Northeast regions had an increase of more than 100% in the number of articles published in the 2016–2020 period when compared to the previous quinquennium.

Most studies involved insect collection on living and dead human bodies (43.1%), while 29.3% involved the use of carcasses, 18.9% used animal baits, 6.9% were theoretical, and 1.7% used marijuana substrate (Fig. 4). The focus of the articles varied from the study of cadaveric fauna (34.4%), insect bionomics (life cycle, duration of larval instars) and wing morphometrics (27.5%), insect diversity on baits and carcasses (15.5%), genetics and molecular biology (15.5%) and insect behavior (especially attraction to ephemeral resources) and reproduction (13.7%). Eleven

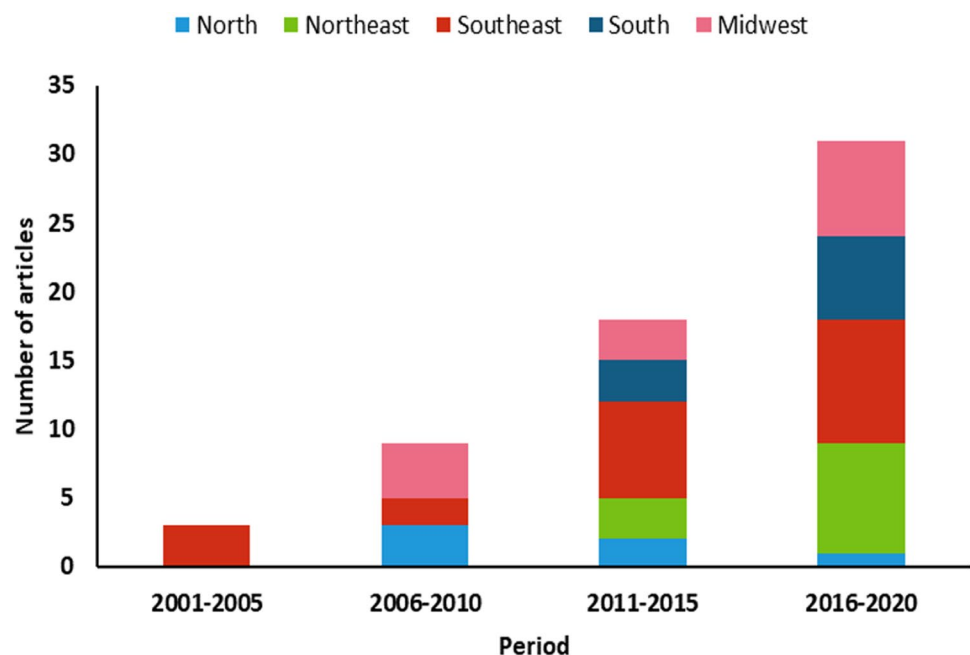
articles (19.0%) specifically aimed at using entomological evidence to estimate PMImin.

Twelve articles (20.6%) addressed forensically relevant Coleoptera species — mainly Scarabaeidae, Cleridae, Dermastidae, and Silphidae, including an article on the effect of carcass decomposition on the colonization by carrion beetles. One article addressed the potential of phytophagous Hemiptera species as indicators of the origin of *Cannabis sativa* in the Midwest region of Brazil. Also noteworthy is the publication of three articles involving hematophagous insects for human DNA identification under a forensic approach.

Most articles (58.6%) were published in journals with Impact Factor (JCR), and this proportion increased by almost 20 times from 2001–2005 to 2016–2020. The most frequently chosen journals were *Revista Brasileira de Entomologia*, *Journal of Forensic Sciences*, and *Genetics and Molecular Research*, which combined, represented 32.7% of all articles. Other journals included *International Journal of Legal Medicine*, *Forensic Science International* and *Australian Journal of Forensic Sciences*.

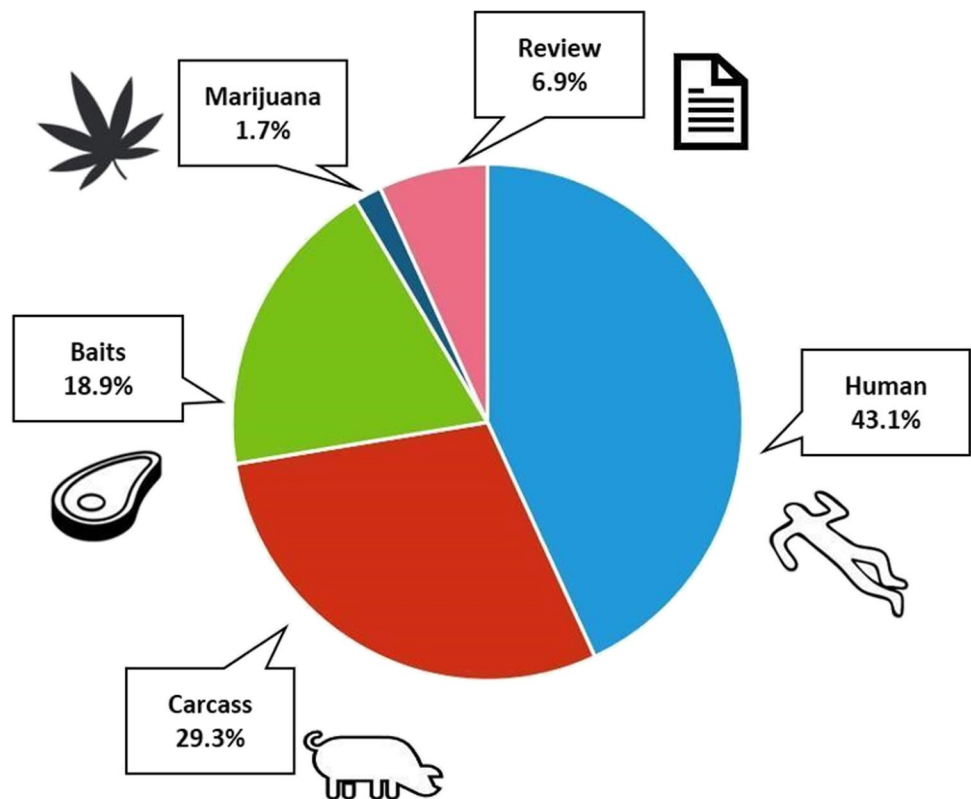
All articles (100%) resulted from research conducted in collaboration with biologists from universities, especially the public ones (84.0%), which are free of charge and maintained by the federal or state government. Almost 50.0% of authors have a degree in Biological Sciences; together, the Medical and Legal Sciences areas represented less than 25.0% of the authors' formal training. Finally, 65.9% of the authors had a post-graduate degree, especially a doctorate, of which 69.0% are in Biological Sciences.

**Fig. 3** Scientific output — number of scientific articles authored by forensic experts in Brazil, according to the region and period





**Fig. 4** Characterization of articles published by Brazilian forensic experts (2001–2020)



## Questionnaire applied to forensic science professionals

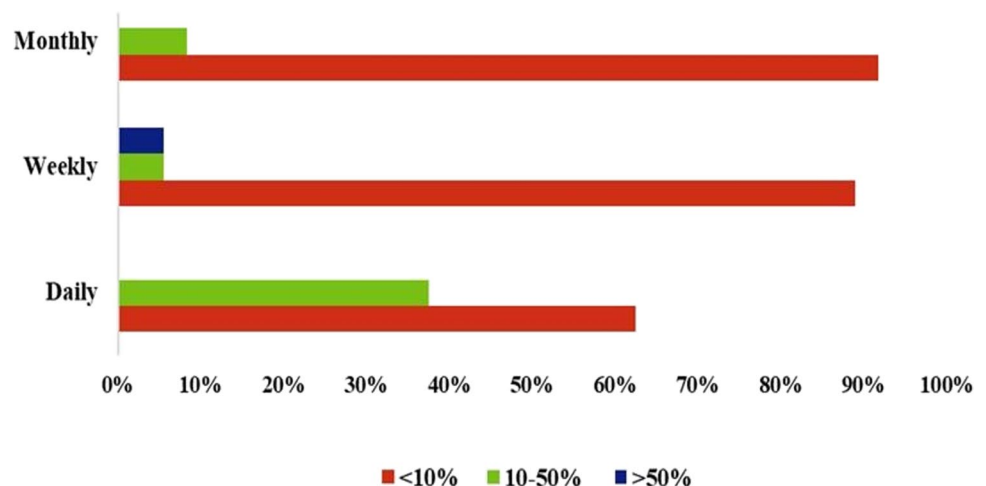
### Scientific training and entomological evidence in the daily practice

Of the 82 respondents, most were criminal experts (75.6%), followed by coroners (12.2%) and autopsy assistants (12.2%). Regarding the level of education of the experts, 61.1% had a post-graduate degree — 31.5% of them had a Ph.D. Overall, 29.0% had an undergraduate

degree in biological sciences; of these, 48.5% had a master's degree and 64.7% had a Ph.D. Also mentioned were Pharmaceutical Sciences (14.5%), Law (14.5%), and Chemistry (6.4%).

Most professionals deal with dead bodies once a week (62.8%). Of these, 74.4% state that less than 10.0% of the handled corpses have insect larvae. Those who deal monthly (14.6%) also reported the same frequency. On the other hand, professionals who examine cadavers daily (19.5% of respondents) find 10.0% to 50.0% colonized by insect larvae (Fig. 5). There was no significant relation between

**Fig. 5** Frequency of handling cadavers in the expert's routine (daily, weekly or monthly) and frequency of encounters of insects as colonizers of corpses collected at the ILM



the frequency of cadaver examination and the likelihood of detecting larvae finding ( $P=0.09$ ). Also, there was no significant correlation between the professional's undergraduate background and the probability of finding cadavers colonized by larvae ( $P>0.05$ ).

### Use of Forensic Entomology by criminal investigators

When asked if there was any procedure related to the collection, handling, or identification of insects present in the corpse, a significant majority ( $\chi^2=30.48$ ;  $P<0.0001$ ) answered negatively (Table 1). Among those who answered affirmatively, the objective of the procedures was to estimate the post-mortem interval (60.0%, equivalent to only ten experts), the collection of viable insects to establish a rearing colony (10.0%), to identify human DNA (10.0%), and to identify the species and the larval instar (10.0%).

Previous experience in using entomological evidence to estimate the PMI was mentioned by only 36.6% of the professionals, although the majority (65.9%) ( $\chi^2=8.24$ ;  $P<0.004$ ) were familiar with educational and research institutions that carry out studies on forensic entomology (Table 1). The vast majority (79.1%) ( $\chi^2=28.09$ ;  $P<0.0001$ ) claimed to have had technical training/opportunities in forensic entomology through courses, workshops, and training (61.2%), lectures (59.7%), scientific events (41.8%), and undergraduate courses and postgraduate studies (38.8%). Positively, we recorded that a significant majority ( $\chi^2=33.00$ ;  $P<0.0001$ ) showed interest in participating in technical-scientific training on FE (Table 1).

### Perceptions on the importance of Forensic Entomology

Most respondents disagree with the statement that Forensic Entomology is not as important as it is advertised in the media ( $\bar{x}=2.0\pm 1.1$ ) (Fig. 6). Still, some state that there is no need for the use of insects in their day-to-day work (although most disagree entirely), a trend seen in the question about FE not having as much importance in issuing reports ( $\bar{x}=2.4\pm 1.3$ ) (Fig. 6).

As for the obstacles to using FE, the difficulty in identifying and breeding the insects are the biggest problems,

with about 60.0% agreement ( $\bar{x}=3.7\pm 1.2$ ). The fact that the articles are written using technical jargon and in English and the lack of time for scientific updating had an average of 3.0 ( $\pm 1.4$ ), showing a variation in responses, being part agreement, part disagreement and part neutrality (Fig. 6).

### Perceptions about legislation regarding the chain of custody

The majority of forensic experts (64.6%) ( $\chi^2=7.02$ ;  $P<0.008$ ) stated that they were aware of changes in the regulation regarding the chain of custody for the collection and maintenance of forensic evidence. Despite this, only 10.1% of the respondents considered that the changes in legislation were discussed in-depth, with ample consultation with interested parties; 34.7% categorized the discussion as superficial, while 31.8% of respondents said they failed to get involved in the discussion about the change in legislation regarding the chain of custody (Fig. 7a).

Over 37.5% of the respondents stated that there are no adequate conditions for maintaining forensic evidence in their institutions, especially physical space and equipment for insect rearing and maintenance. Only 18.7% claim that their institutions fully comply with the chain of custody conditions contained in the new legislation (Fig. 7b).

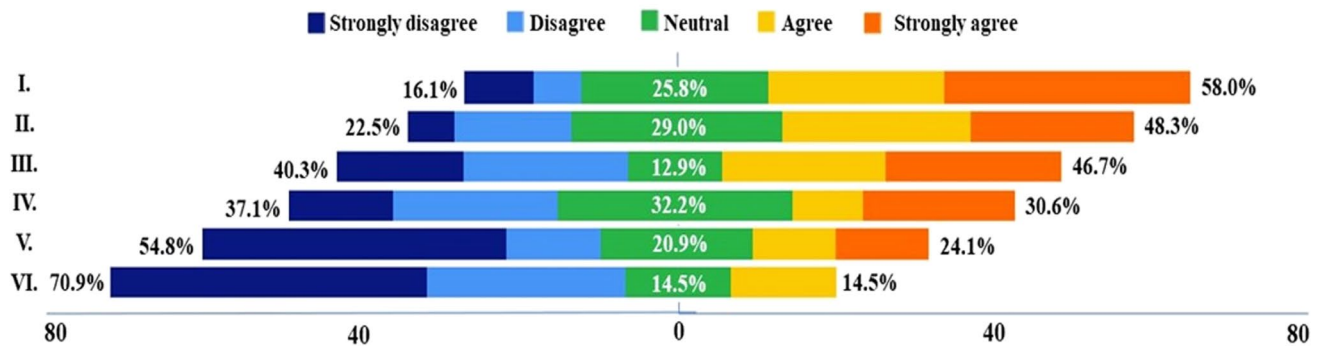
When asked about the main changes in the chain of custody, 46.3% of the respondents cited as contributions the installment of custody centers and better traceability of the trace as main points. Around 15.8% said they had no opinion, either because they were not sufficiently informed about the new law or because their work was not directly affected by it (Fig. 8).

Half of the respondents did not comment on the new legislation on chain of custody concerning Forensic Entomology. Among those who answered, the following positive points were cited: the standardization of procedures, making them more reliable; better control and preservation of evidence through correct storage; storage of data that could be used in internal reports; providing material for more accurate technical reports for other institutions, including partnerships. The forensic experts

**Table 1** Professional training and handling of cadavers colonized by insects, according to Brazilian forensic experts (N=82)

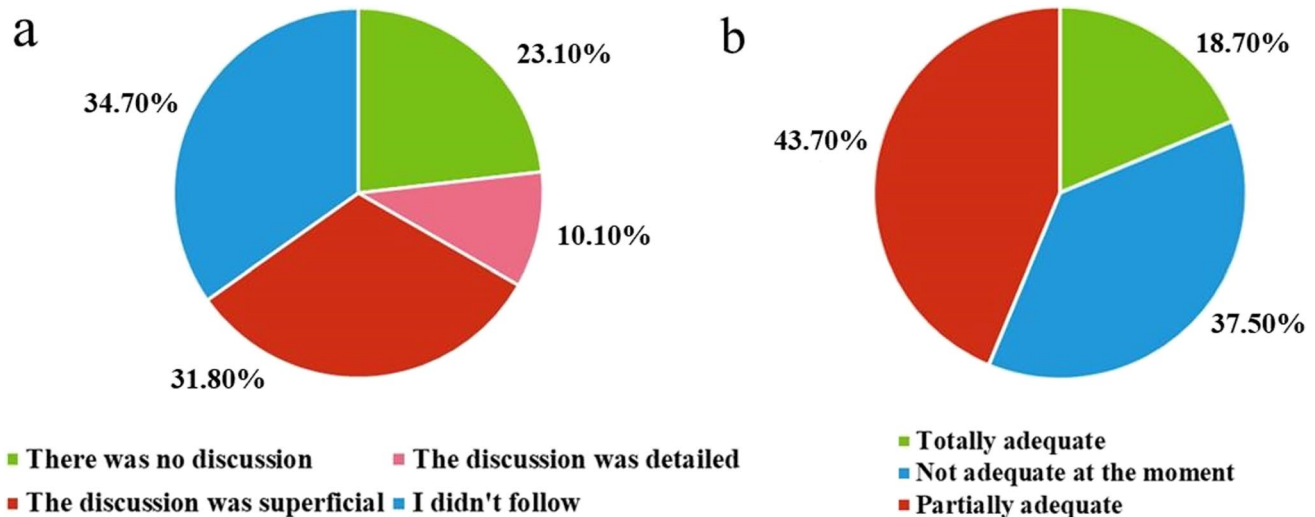
Question	Yes	No
When insects are present in cadavers, is there any type of procedure related to their collection, handling or identification?	19.5%	80.5%
Have you ever used information about insects to estimate the post-mortem interval?	36.6%	63.4%
Do you know any institution that develops studies on Forensic Entomology in Brazil?	65.9%	34.1%
Have you ever had the opportunity to receive technical information (courses, workshops, etc.) on Forensic Entomology?	79.1%	20.9%
Would you be interested in participating in continuing education on Forensic Entomology practices?	81.7%	18.3%

- I. The main obstacle in using Forensic Entomology is the difficulty in handling and rearing insects.
- II. The main limitation in the use of Forensic Entomology is estimating the PMI in is the difficulty in identifying the insects.
- III. Lack of time is the main limiting factor for my involvement with Forensic Entomology.
- IV. I would read more about Forensic Entomology if there were more articles in Portuguese aimed at the non-specialized reader.
- V. In my daily practice there is no need to use knowledge about insects when issuing reports.
- VI. Forensic Entomology is not as important in issuing reports as it often disclosed in movies, lectures and TV series.



**Fig. 6** Criminal experts' perception of the importance of entomological evidence and main obstacles to the consolidation of forensic entomology in Brazilian legal medicine institutes. Values at the left and

right represent the sum of percentages of 'disagreement' and 'agreement' answers, respectively



**Fig. 7** Criminal experts' perception of (a) the debate on the implementation of the new legislation on the chain of custody and (b) conditions for maintaining expert evidence (including biological samples) in their work institutions

expressed two major concerns: the lack of training for the correct use of the chain of custody and the lack of specification of collection techniques. The professionals also expressed doubts about how the rearing and identification of insects would be made possible, as it would be time-consuming, and the institutions would need to have the necessary conditions for these procedures.

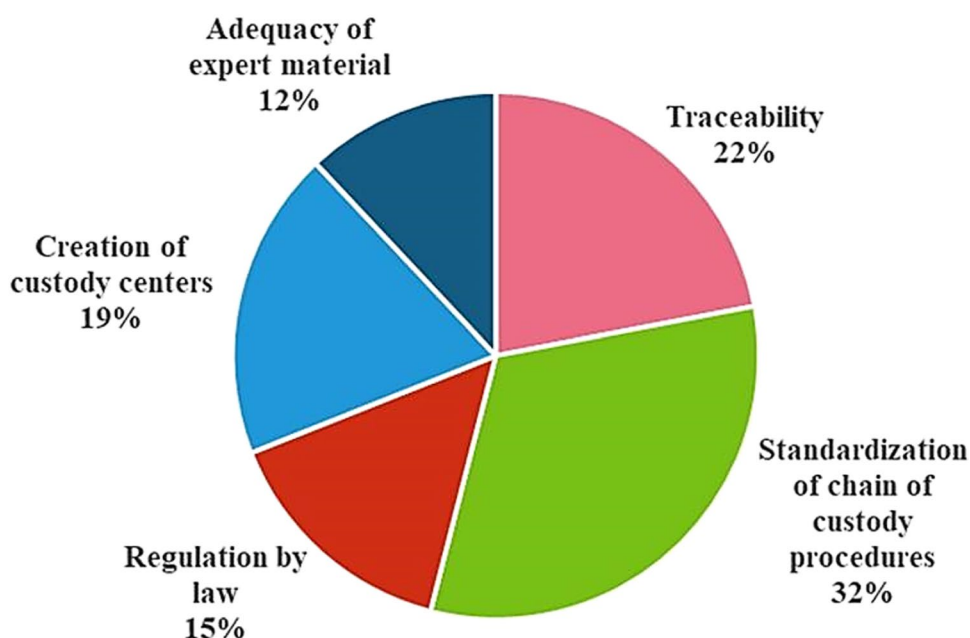
## Discussion

### Do forensic experts produce "real" science in Brazil?

The survey reveals a promising scenario of forensic experts' involvement in scientific research — and their



**Fig. 8** Forensic experts' perceptions regarding the main changes in the new chain of custody legislation in Brazil



interaction with the academic community — in a country exposed to alarming rates of homicides. We consider the number of publications on Forensic Entomology to be below the tremendous potential of entomological evidence in criminal investigations. Nevertheless, Brazilian experts used insects to infer about conditions of death (e.g., outdoor × indoor environments), the PMI and the type of death (e.g., by hanging). Advances in techniques of molecular biology are reported, such as the detection of human DNA in Calliphoridae larvae. An article that investigated the origin of drugs through insect fragments in compacted hemp, using a little-studied group of insects in forensic entomology (Hemiptera: Pentatomidae), contributed to excluding some growing areas from the expected route of traffic [15]. This opens exciting possibilities for border police patrol, given that Brazil was the third country in the number of apprehensions of marijuana in South America in 2019 [16].

The excessive workload of forensic experts in Brazil leaves limited time for academic activities — particularly writing scientific articles. Writing up work for publication is a time-consuming business, and talent as a crime scene examiner does not always correlate with talent as a writer [17]. The strict requirement of English language mastery — something hardly accessible to non-native researchers worldwide [18] — and the prohibitive fees for publication in many journals limit opportunities for publication. To support this assumption, we found 34 papers published by Brazilian forensic experts in free of charge and non-indexed periodicals in Portuguese. Although they contribute less to the international dissemination of the findings, these articles fulfill the objective of sharing experiences with Brazilian

peers. Nevertheless, there is an increment in the quantity and quality of publications in journals with impact factor, aiming at the socialization of knowledge with the international community. Publications in journals with IF represent a significant advance, as they undergo peer review and reach a wider audience [17]. In some countries, the allocation of government funds and career advancement depends on these publications [19].

The uneven distribution of articles by geographic region is not proportional to homicide rates (Fig. 1) and may result from the overload of cases for professionals in certain regions due to a gigantic disparity in the number of professionals, the difference in the training of experts, or to the proximity to consolidated research centers. To illustrate that, the Southeast region has more than twice as many forensic experts as the North and Northeast regions, which have higher homicide rates [20].

This disparity among states is not endemic to Brazil: a survey of forensic entomology literature in the USA showed that experts based in Maryland produced 30 times more papers than those in Delaware and Vermont [21]. Despite the intrinsic difficulties faced by Brazilian scientists, a recent bibliometric study lists Brazil as the country with the second-highest scientific output in forensic entomology in the world [9]. Interestingly, works by authors exclusively linked to the police are few in relation to this total, indicating a predominance of articles resulting from strictly university-based research.

According to Jones [17], most forensic scientists' publication production is dismal when compared to university-based scientists of the same age and qualifications. Brazil follows the pattern, given that all 58 articles resulted from

collaborations with universities, especially the public ones, which are free of charge, maintained by the federal or state government and comprise virtually all programs of excellence in Brazil. With few exceptions, the articles resulted from forensic experts' post-graduate (M.Sc., Ph.D.) projects. For comparison, in Egypt, a country with millenary wisdom on legal medicine, academic members perform research in collaboration with the Forensic Medicine Authority, and their studies are published in international journals [22].

Criteria for the career advancement of the police staff include participation in courses, recognition by peers and superiors, post-graduation titles, achievement of goals (e.g., elucidated crimes), involvement in tutoring, management positions, among others. In Brazil, the valorization of scientific research in the criminal expert's routine — particularly the publication of articles — is undervalued, with minimal impact on career advancement. Publishing scientific articles should be more valued in forensic scientists' career development, which today is not the case [17].

### **Do Brazilian forensic experts use entomological evidence in daily practice?**

The profile of Brazilian criminal experts has similarities with professionals from other parts of the world. Brazilian experts generally have a post-graduate degree in Biological Sciences, reflecting their interest in Forensic Biology. The requirements for working as a criminal expert (or crime scene examiner) vary from country to country, and the few reports available indicate similarities to the context of the USA [23], Egypt [22], Sub-Saharan Africa [24] and Spain [25]. Forensic science technicians in the USA need to hold a bachelor's degree in natural science (such as biology and chemistry) or forensic science as a minimum education [26]. In the case of CSI (Crime Scene Investigator), having a degree in forensic science, biological sciences, chemistry, criminology, and psychology is advantageous in selection [27]. Similar to Brazil, these professionals receive specific training after being hired.

Admission to the scientific police occurs through a disputed public competition and requires a bachelor's degree. Master's and doctoral degrees influence approval and career progression, including financial terms — similar to the USA [17]. In our study, almost 25% of respondents have a maximum degree (Doctorate), considerably larger than other police forces in Brazil. The proportion of doctors is close to what was observed in a worldwide survey among forensic entomologists in which 23.5% of 69 respondents had a Ph.D. — but that international sample mainly consisted of academic researchers [11]. Surprisingly, no Brazilians were represented in that study.

According to the Global Peace Index [28], Brazil has the highest rates of homicide and violent crime, overloading

the daily routine of professionals, who primarily deal with cadavers in Institutes of Legal Medicine at least once a week. The uneven geographical distribution of forensic experts across Brazilian states is also reported for Sub-Saharan African countries [24], the USA [10], and China [29]. As a positive effect, we perceive a tendency to decentralize research centers and the installment of legal medicine institutes in municipalities distant from major cities in Brazil.

Although some respondents have used insects in investigations through PMI and DNA traces, they point out difficulties in handling and identifying insects since their background in biological sciences does not necessarily indicate specialization in entomology. In Spain, for comparison, forensic entomology presents additional difficulties because it is considered a supplementary technique, and the collection of entomological evidence can only be done by medical examiners and by the police officers responsible for the visual inspection of cadavers [25]. In that country, few professionals are willing to spend the time and effort to collect entomological evidence, and with very few exceptions, neither police officers nor medical examiners have been appropriately trained for entomological purposes [25].

Likelihood of encountering necrophagous larvae may be biased by the person responsible for the evidence collection. In a comprehensive study involving almost 1000 cadavers in Germany, in only 30% of the cases the insects were identified, and in 15% of the cases the entomological report was written [30].

In sub-Saharan Africa, death investigation systems suffer from insufficient scene protection, inadequate facilities, and poor staff qualification and training [24]. Even in countries with a long history of forensic entomology, such as the UK, several reports highlight that the forensic science training received by police officers is inadequate, resulting in a limited understanding of the potential contribution of forensic science to an investigation [31].

Forensic investigators registered a low frequency of encounters of cadavers colonized by insects (10%), which is explained by the increasing efficiency of the crime scene protocols. Homicides are quickly reported to the authorities (e.g., through anonymous emergency phone numbers), and, according to experts from Northeastern Brazil, almost 90% of the cadavers are found within 48 h post-mortem [1]. This causes cadavers to be exposed for limited time to decompose and attract insects, which is why the PMImin estimate is made regularly based on legal medicine signs. Not surprisingly, nearly 75% of respondents claim that entomological evidence is not as sound as reported, and more than 50% of respondents assert that there is no need for entomological evidence to estimate the PMI.

Evidence feasibility in the different stages of the evidence-gathering process, i.e., from the moment of deciding what evidence should be obtained to using it in the

courtroom, or the entire ‘chain of custody’ is pursued in many countries [32]. In that sense, recent initiatives by the United Nations aim to strengthen competencies on crime scene investigation among Tunisian criminal experts — and the steps of the chain of custody are a central part of the training [33].

Most Brazilian experts in this survey are aware of the changes in the regulation of expert procedures but consider that the discussion about the process could have been in greater depth. The respondents assess that their institutions have only partially adequate conditions for maintaining evidence in accordance with the new law. Since it is a recent alteration, many professionals are still adapting to the changes and training themselves, and institutions need to organize and implement custody centers, which takes time, money, and personnel.

The negative assessment of Brazilian experts on infrastructure associated with scientific research and the chain of custody echoes the reality in many countries. In Sub-Saharan Africa, Obenson and Orock [24] described similar obstacles: limited space that hinders the examination activities, the preparation of samples for analysis, and the storage of remains. Participants often emphasized the precariousness of their facilities and equipment, sometimes citing the lack of even essential items such as ventilation systems and sewage.

Brazil’s Ministry of Public Security offers continuing education in several areas of criminal forensics, and recently (2021) launched a specific course to help professionals work in line with maintaining the chain of custody [34]. The experts stated interest in courses, workshops and specific training in Forensic Entomology. However, similar to the UK [35], forensic science training courses in Brazil lack standardization, with variable content and length.

Lastly, investment in forensic intelligence is crucial to guarantee standardization, accreditation, and de-contextualization, in a legal and economic context, in order to ensure the scientific objectivity and efficiency that must guide the process of collecting, analyzing, interpreting, and reporting forensic evidence [36].

## Final considerations

Public communication of advances in forensic sciences is fundamental for strengthening reliable procedures in criminal investigations. The number of articles denotes the development of a topic based on bibliometrics, and the steady increase in the publication by Brazilian forensic experts in the last years makes for an optimistic scenario. The considerable scientific output in new research centers will add diversity – e.g., peculiarities of different

environments – in a country with continental dimensions such as Brazil. Further studies on the profile of forensic experts in other countries are needed to build a thorough, worldwide scenario of practical use of forensic entomology.

The use of entomological evidence in criminal investigations (e.g., estimation of PMImin) by Brazilian forensic experts is scant – but this does not necessarily relate to a limited understanding of the importance of insects as pieces of evidence. In a reality of dozens of homicides per month to be investigated, it is comprehensible that collecting, rearing, and identifying necrophagous insects may not be a priority. Interestingly, unrealistic public expectations about the investigative value of insect evidence – perceived by Brazilian investigators as engendered by television crime programs – were also acknowledged in a survey among Canadian police investigators [37].

In Brazil, it is expected that the regulation of the chain of custody will refine criteria for the validation and reliability applied to all stages in the collection, storage, and use of evidence, as proposed by Kotzé et al. [38]. On a cautionary approach, we fear for changes promoted by the Brazilian presidential decrees that facilitate access to guns. Blurring the distinction between legal and illegal markets will benefit organized crime and paramilitary groups – and thus make Brazil less safe for everyone, including law enforcement professionals [39].

Collaboration between scientists at universities and the crime scene examiners has been advocated in countries as diverse as Brazil [1, 40] and the United Kingdom [35]. The strengthening of communication between the parties will bring robustness to the use of insects in investigations, obtain more accurate PMI estimates based on local data, enhancing the reliability of the evidence. Finally, we are optimistic about the emergence of new research centers developed in other country regions, and the development of networks among forensic entomologists worldwide.

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## Declarations

**Ethics approval and consent to participate** All respondents to our survey explicitly authorized using data obtained in the questionnaires for publication.

**Consent for publication** All authors read and approved the submitted version.

**Conflict of interest** The authors declare no competing interests.

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