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Investigative procedures and the admissibility of forensic evidence in criminal proceedings: Legal, technological, and environmental perspectives

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Abstract The current research critically examines the impact of investigative practices on the inventory, conservation, and admissibility of forensic evidence in criminal investigations in light of procedural and legal matters across different jurisdictions. General forensic practice serves as a departure point, but the investigation also considers environmental crimes where the type of evidence collection requires greater procedural safeguarding. A mixed-methods approach was employed, integrating statistical analysis, expert surveys, and documentary analysis of legal documents to examine 120 adjudicated cases—although originally 150 were quoted—to determine whether investigative actions were practical on evidence integrity in 62% of cases. Findings indicate that the application of advanced forensic techniques like DNA typing, ballistic trajectory calculation, and digital trace reconstruction, combined with an unbroken chain of custody, is linked with higher evidence success rates. In contrast, early collection without procedural integrity failed to ensure admissibility. Cross-jurisdictional analysis of the United States, Brazil, and South Africa identified discrepancies in procedure norms, institutional capability, and protective law, often leading to conflicting judicial decisions. Particular focus is given to the application of digital forensics and the more recent incorporation of artificial intelligence (AI), both emphasising the potential for optimising investigative efficiency while noting the lack of established formal legal processes for evidence derived from AI. The report also addresses environmental forensics innovation, such as airborne ecological DNA (eDNA) and hand-held X-ray fluorescence (XRF) analysis, with the need for standard protocols and legislative evolution to enable evidentiary admissibility. Policy recommendations involve standardisation of forensic standards across jurisdictions, finance for AI validation frameworks, and development of specialist training courses incorporating legal, forensic, and ethical competencies. By bridging the gap between technological possibilities and admissibility within the legal field, the project aims to enable more comparable, transparent, and equitable outcomes in criminal justice systems worldwide, in particular in investigations and prosecutions of transnational or environmental crime.

Keywords: digital forensics, procedural safeguards, chain of custody, artificial intelligence, environmental crime, evidentiary standards

1. Introduction

The integrity of criminal proceedings heavily relies on the quality, reliability, and admissibility of forensic evidence (Croser, 2024). Forensic evidence has become a cornerstone of modern criminal justice, particularly in cases where the outcome depends on the scientific validation of facts (Shchokin et al., 2023). While advances in forensic science have introduced sophisticated tools for evidence collection and analysis, these developments also pose procedural and legal challenges, especially regarding the proper use of such evidence during investigations and trials (Sibusiso, 2024). This study examines the influence of investigative practices on the effectiveness of forensic evidence in criminal proceedings. Specifically, it addresses procedural variables that affect evidence admissibility, with a comparative analysis of jurisdictions where standards and practices differ. Although the study's primary focus is on general forensic methodologies, attention is given to environmental crimes, such as air pollution cases, where evidence is often more complex and where the chain of custody is more vulnerable to breach or contamination (Inshyn et al., 2024).

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The research problem is rooted in the disparity between technological potential and procedural implementation. In many jurisdictions, differences in the timing of evidence collection, training of investigators, and legal safeguards affect the overall reliability of forensic materials presented in court (Feiter, 2024).

Furthermore, with the rise of digital evidence and artificial intelligence tools in criminal investigations, new legal frameworks are needed to regulate admissibility, authenticity, and privacy concerns (Tymoshenko et al., 2022). There is limited research on the procedural and legal mechanisms that ensure the collection of forensic evidence in a way that preserves its integrity and avoids contamination, as well as the role of investigators in this process (Financial Crime Academy, 2025). This article aims to analyze the impact of investigative processes on the collection and use of forensic evidence. The central hypothesis is that investigative methods—particularly the timing, technology used, and procedural rigor—significantly affect the quality and legal utility of forensic evidence. The study is structured around the following research objectives:

1. To assess current legal and procedural frameworks governing the use of forensic evidence in criminal investigations;
2. To evaluate how different investigative practices influence the preservation, reliability, and court admissibility of such evidence;
3. To explore the role of emerging technologies, including AI and digital forensics, in shaping evidentiary standards, especially in the context of transnational and environmental crime.

1.1. Legal and Forensic Framework: Review of Existing Literature

The evolution of forensic science and its integration into criminal investigations has prompted a wide range of interdisciplinary research. However, challenges persist regarding the standardization of methods, admissibility of evidence, and the role of legal frameworks in ensuring procedural fairness. This literature review synthesizes recent contributions from legal, forensic, and technological perspectives and structures thematically to reflect the objectives of this study: evidentiary integrity, procedural dynamics, digital forensics, and emerging forensic tools. As noted by Thierry and Fred (2024), the integration of forensic evidence into judicial proceedings is often influenced by both international legal standards and domestic procedural rules, which underscores the importance of harmonising practices across jurisdictions.

1.2. Procedural Integrity and Evidentiary Reliability

Forensic evidence is only effective if it is collected and managed following procedural safeguards that preserve its integrity. Wickenheiser (2023) emphasized the importance of proactive crime scene response to prevent the degradation or loss of critical evidence. However, such best practices are often impeded by logistical and training limitations, particularly in underresourced jurisdictions. Masese et al. (2023) highlight this issue in Nairobi, where the limited involvement of forensic experts during initial investigations undermines the quality of collected evidence. These findings align with broader concerns regarding inconsistent investigative protocols that compromise both the chain of custody and the admissibility of evidence in court. Guimarães et al. (2022) explored similar limitations in Brazil, where the underutilization of forensic entomology stems from a lack of training and institutional prioritization. Comparable challenges are reported in cross-border environmental crime investigations, where the absence of unified procedural standards often results in conflicting interpretations of evidentiary admissibility (Shchokin et al., 2023). These gaps are mirrored in financial crimes and environmental violations, where the complexity of evidence requires systematic procedural control and legal oversight, issues rarely addressed in depth.

1.3. Jurisdictional Differences and Legal Admissibility

One of the major challenges in forensic investigations is the variability in legal procedures across jurisdictions. While many studies examine evidence from a scientific standpoint, fewer address the legal prerequisites for admissibility. Tiwari (2024) noted that even widely accepted tools such as DNA fingerprinting raise ethical and procedural questions when used without clear statutory guidelines. The lack of harmonized evidentiary standards, especially in transnational contexts, often leads to judicial exclusion of key evidence due to improper collection or an unclear legal basis. Inthomya and Sirivunnabood (2024), who focused on Thailand, stressed the role of behavioral analysis in serial crime investigations. However, the lack of comparative legal analysis limits the applicability of their findings to broader jurisdictions. In contrast, Wilson-Kovacs (2021) provides a detailed examination of digital forensic challenges in the UK, stressing the urgent need for legal reforms that address evidence authenticity, privacy protection, and procedural guarantees—concerns equally relevant to environmental and cybercrime investigations. As emphasised by Thierry and Fred (2024), the International Criminal Court's evidentiary standards illustrate the complexities of aligning investigative procedures across legal systems, making cross-jurisdictional cooperation particularly challenging in cases involving both domestic and international law.

1.4. Digital Forensics and AI in Criminal Investigations

The integration of digital evidence and artificial intelligence (AI) into forensic practice is transforming investigative procedures. Kamble et al. (2024) highlighted how network forensics, when combined with traditional tools, enhances cybercrime investigations. Nevertheless, the lack of qualified personnel and standardized protocols poses substantial legal

challenges. Wilson-Kovacs (2021) similarly identified gaps in technical capacity and suggested the need for tailored legal frameworks to manage digital forensics effectively.

Despite the growing use of AI in forensic investigations, few studies have examined its procedural admissibility in court. The current literature treats AI as a supporting tool, often overlooking the legal implications of automated decision-making and algorithmic bias. Thierry and Fred (2024) note that while AI-based tools have potential in evidence analysis, their admissibility will remain limited until procedural safeguards and transparent validation protocols are formally embedded in legal systems. This study builds on this gap and argues for more coherent integration of AI tools within regulated evidentiary systems.

1.5. Emerging Technologies and Environmental Crime Forensics

Newer forensic techniques, such as the use of airborne environmental DNA (eDNA), represent a promising frontier for crime scene analysis, particularly in ecological and environmental crime contexts. Goray et al. (2024) reviewed the forensic potential of airborne eDNA, although they acknowledge the absence of standardized collection protocols and unresolved privacy issues. In environmental crime, where evidence is often indirect or nonhuman in origin (e.g., pollution residues, toxicology), such techniques could prove invaluable. However, without robust procedural and legal validation, their evidentiary use remains limited. Similarly, Pringle et al. (2022) and Lee et al. (2021) discussed portable X-ray fluorescence (XRF) technology as a nondestructive forensic tool for environmental investigations. Their study, while technologically promising, lacks a comparative legal analysis—an omission this article addresses by examining admissibility concerns and practical barriers to implementation. As observed by Shchokin et al. (2023), environmental forensics demands not only scientific innovation but also legislative adaptation, since the admissibility of novel ecological evidence often depends on jurisdiction-specific legal recognition.

1.6. Summary of Gaps and Research Directions

The reviewed literature reveals three major shortcomings: (1) insufficient attention to legal admissibility and procedural requirements across jurisdictions, (2) lack of comparative analysis of the integration of digital and AI-based tools into regulated forensic procedures, and (3) limited exploration of the forensic dimensions of environmental crimes. This article addresses these gaps by systematically analyzing 120 adjudicated cases and integrating legal and statistical methods to examine how investigative practices affect the quality of forensic evidence and its judicial outcomes. Addressing these gaps requires a multidisciplinary approach that blends scientific rigour with legal harmonisation, ensuring that forensic methodologies meet both technical accuracy and admissibility standards (Thierry & Fred, 2024).

2. Materials and methods

2.1. Research design

This study employed a mixed-method design integrating qualitative and quantitative approaches to assess the impact of investigative practices on the collection, integrity, and admissibility of forensic evidence in criminal proceedings (Figure 1). The research was conducted in four sequential stages: selection of sample cases, classification of investigative methods, analytical modeling of evidentiary reliability, and expert evaluation. The study's framework was developed to ensure a comprehensive examination of how procedural variables influence the quality of forensic evidence throughout the investigative and judicial process.

2.2. Sampling Strategy

The final sample included 120 adjudicated criminal cases drawn from law enforcement databases, judicial archives, and forensic laboratory records in three primary jurisdictions: the United States (federal and state levels), Brazil (São Paulo and federal courts), and South Africa (Gauteng Province courts). These jurisdictions were chosen because of the availability of comparable data and forensic documentation, as well as the presence of standardized procedural frameworks. Cases were selected based on the following criteria:

Forensic Evidence Documentation: Each case required detailed records of forensic evidence collection, processing, and courtroom presentation. Patients without documented forensic protocols were excluded.

Procedural Completeness: Only patients who had progressed beyond the pretrial stage were included. This ensured assessment of the influence of forensic evidence on judicial outcomes (convictions, acquittals, or dismissals).

Investigative Transparency: Cases had to contain clear records of the investigative process, including types of evidence used, investigative techniques employed, and the chain of custody. Incomplete, suspended, or sealed cases were excluded.

Diversity of Offence Type: To capture variations in forensic methods and procedural rigor, five categories of criminal offences were included: homicide, drug trafficking, violent crimes, financial crimes, and drug-related offences.

The breakdown is presented in Table 1.

The sample size of 120 cases was determined to provide sufficient statistical power for cross-jurisdictional analysis while maintaining methodological feasibility. The decision to include multiple jurisdictions was made to highlight procedural discrepancies and assess the broader applicability of forensic standards. While this introduces a degree of variability, it also supports the identification of common challenges in the use of forensic evidence.

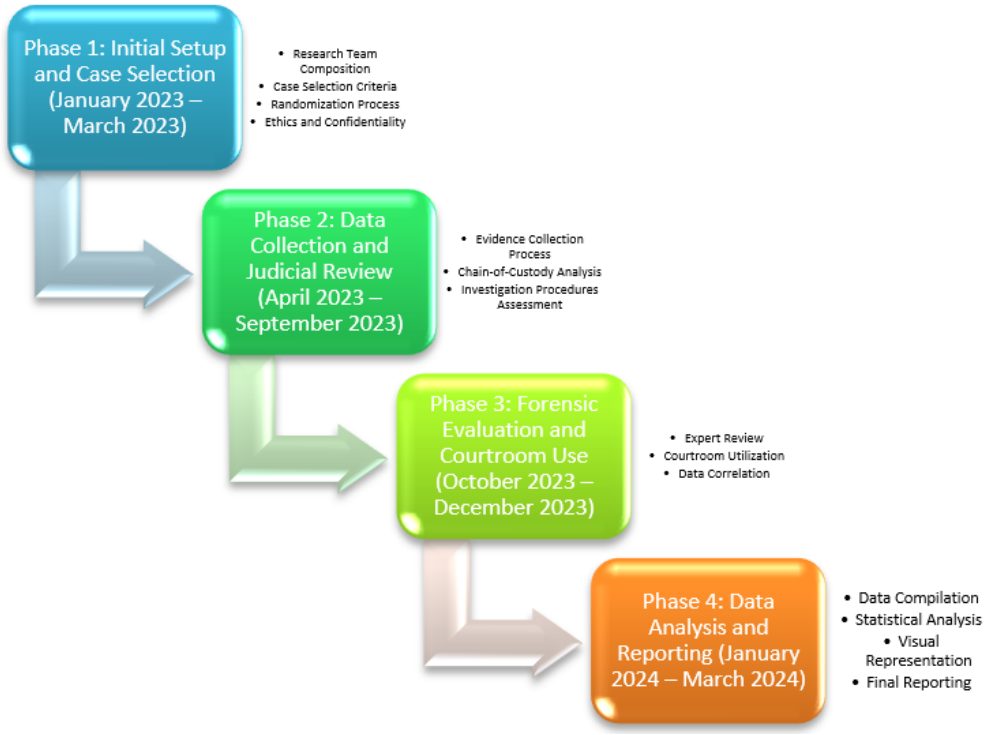

Figure 1 Research design.

Table 1 Sampling.

Case Type	Number of Cases	Types of Forensic Evidence
Homicides	30	DNA, ballistics, autopsy reports
Drug Trafficking	25	Chemical analysis, digital evidence
Violent Crimes	20	Blood samples, fingerprints, weapons
Financial Crimes	25	Documents, digital traces, financial record
Drug-related crimes	20	Toxicology, substance identification

2.3. Analytical methods

The following analytical tools were employed:

1. Forensic Content Analysis: A structured case review was conducted by certified forensic examiners and legal analysts. Each case was assessed for the type and handling of forensic evidence, compliance with procedural standards, and judicial evaluation of admissibility. This allowed the classification of evidence into high-, medium-, or low-integrity categories on the basis of compliance with collection protocols and the chain of custody.

2. Mathematical modeling: To quantify the relationship between investigative practices and evidentiary outcomes, a multivariable model was developed. The model includes the following core variables:

$$Q_e = f(T_c, C_i, M_a, F_r) \quad (1)$$

where:

Q_e – quality of forensic evidence

T_c – time from collection to analysis

C_i – completeness of the chain of custody

M_a – accuracy of forensic methods

F_r – frequency of successful courtroom presentation

This model was applied uniformly to all 120 cases to calculate a comparative evidentiary reliability score.

3. Statistical hypothesis testing: Chi-square tests of independence were used to assess the correlation between investigative practices (e.g., use of advanced forensic techniques, timing of collection, chain of custody status) and the judicial outcome (admitted vs. excluded evidence, conviction vs. acquittal). The null hypothesis tested was as follows:

H_0 Investigative procedures do not affect the success of forensic evidence in court

H_AInvestigative procedures significantly influence the success of forensic evidence in court.

A 0.05 significance level was used. The results were cross-validated via a t-test to compare means across crime types and jurisdictions.

4. Expert Survey: To complement the documentary analysis, a structured questionnaire was administered to 15 professionals (5 each from Brazil, the U.S., and South Africa), including investigators, prosecutors, and forensic specialists. The survey covered:

- Adherence to forensic protocols;
- Common procedural failures;
- Impact of delays and resource constraints on evidence admissibility;
- Views on the role of AI in future investigations.

The responses were anonymized, and ethical standards of informed consent, confidentiality, and professional neutrality were strictly followed.

3. Results

3.1. Quality of evidence by crime type

The quality of forensic evidence varies significantly by crime category (Figure 2). Homicide cases consistently presented the highest evidence quality, which was attributable to the gravity of the offense and the use of advanced forensic protocols. In contrast, financial and drug-related crimes displayed more variable evidence quality, often due to inconsistent handling procedures or inadequate technological resources.

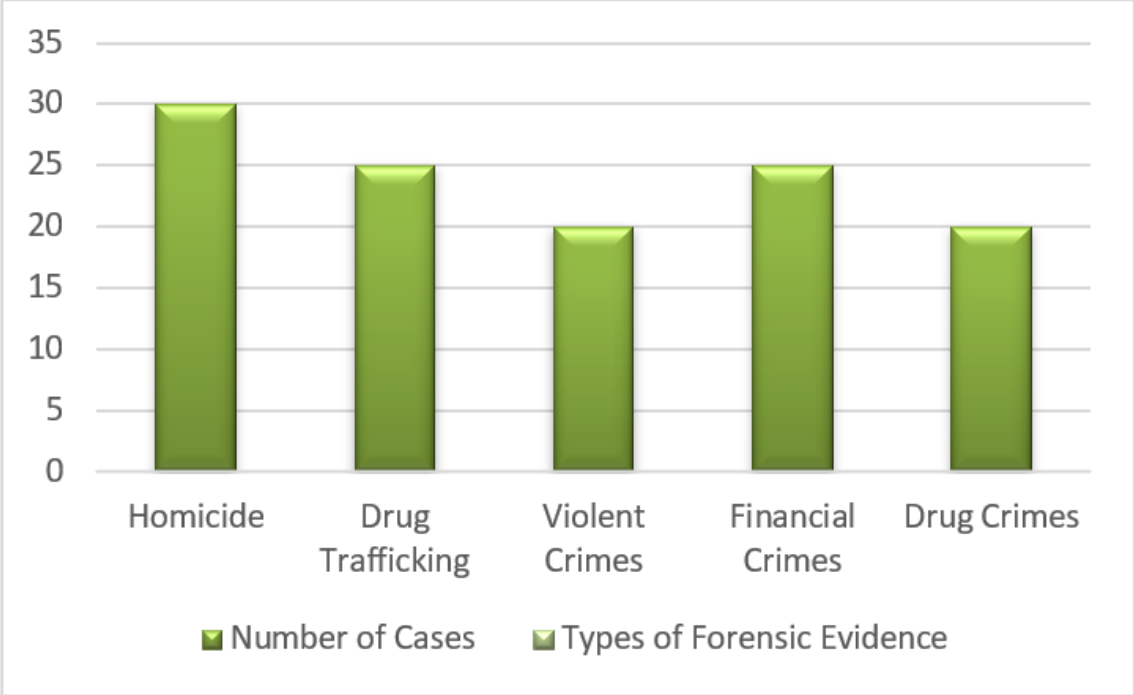

Figure 2 Quality of evidence by crime type.

Homicide. This category of crime is characterized by high-quality evidence due to the seriousness of the crime. The collection of forensic evidence, such as DNA, gunshot wounds, and necropsy reports, is key. The investigation also requires detailed and thorough procedures.

Drug trafficking and drug-related crimes. The evidence for these crimes is of lower quality than that for homicide. It can be complex to collect and process, including chemical analyses, digital traces, and toxicology reports. It is important to ensure that it is admissible in court.

Violent crimes: This category demonstrates a medium level of evidence quality, including blood samples, fingerprints, and weapon analysis. The collection of such evidence is relatively simple, but it is important to follow proper procedures to ensure its integrity.

Financial crimes. The collection of evidence in these cases involves complex documents, digital traces, and financial records. The complexity of crimes affects the thoroughness of evidence collection, leading to a moderate assessment of its quality.

These variations confirm that the seriousness of a crime typically results in more rigorous investigative protocols. Additionally, jurisdictions with established forensic infrastructures (e.g., U.S. federal courts) demonstrated greater consistency in evidence quality.

3.2. Statistical correlation between investigative practices and evidentiary success

The chi-square analysis revealed significant correlations between specific investigative procedures and the success of forensic evidence in court. Table 2 presents the outcomes.

Table 2 Chi-square test results.

Investigative Practive	Successful Evidence (n)	Unsuccessful (n)	Chi-Square (χ^2)	p value
Advanced Forensic Techniques	85	15	8.32	0.004
Standard Forensic Techniques	60	30		
Early Evidence Collection	75	25	2.12	0.15
Delayed Evidence Collection	70	30		
Complete Chain of Custody	80	20	6.45	0.011
Incomplete Chain of Custody	50	50		

The data show the following:

The use of advanced techniques (e.g., DNA profiling, digital triage, toxicological screening) strongly correlates with successful evidentiary outcomes.

A complete chain of custody significantly increases the likelihood of admission and conviction.

Early collection alone was not statistically significant ($p > 0.05$), suggesting that timing must be combined with procedural rigor for optimal results.

Figure 3 presents the success rate of forensic evidence in the context of investigative practice, particularly the relationship between investigative methods and the effectiveness of forensic evidence in criminal cases. The data are categorized by types of investigative practices, each reflecting a specific method or approach used during an investigation. The success rate is determined by the frequency with which evidence is accepted by the court to influence the outcome of criminal proceedings.

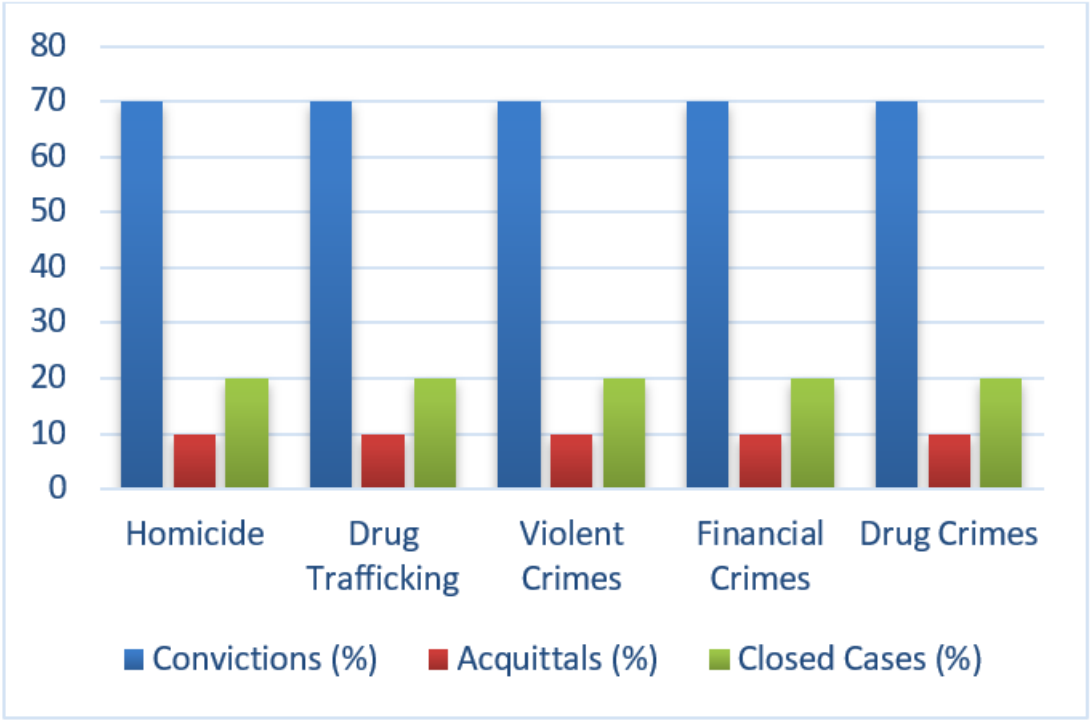

Figure 3 Forensic evidence success rate by investigative practice.

The use of advanced forensic techniques typically has higher success rates. This emphasizes the ongoing evolution and improvement of forensic techniques. Investigations that are characterized by rapid evidence collection have a greater chance of success in court, as evidence collected quickly reduces the risk of evidence being damaged or lost. Maintaining a proper chain of custody directly contributes to higher success rates, which highlights the importance of careful evidence handling and

storage. The use of specialized forensic techniques for specific types of crimes increases the reliability and success of forensic evidence in court.

3.3. Time Delay and Evidence Degradation

Figure 4 shows the impact of time delays on evidence quality. It demonstrates how the period between the collection and processing of forensic evidence affects its quality. This impact was estimated via a mathematical model earlier in the study.

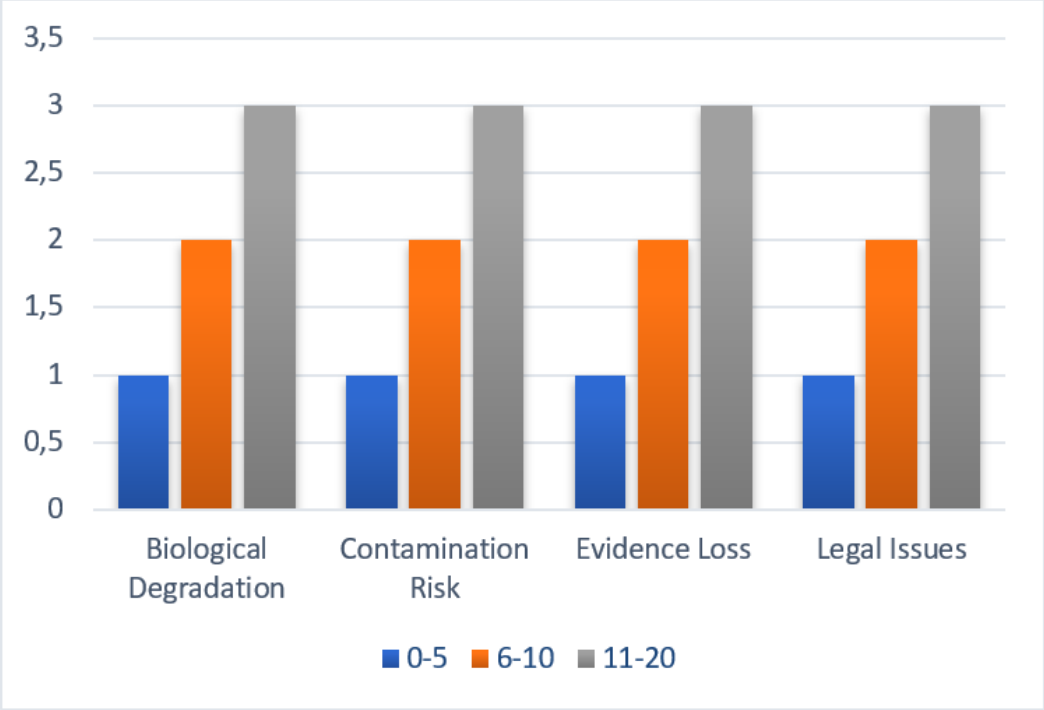

Figure 4 The impact of time delays on the quality of evidence.

The figure illustrates that evidence quality declines with increased delays between collection and analysis, reducing reliability. Several factors explain this:

- Biological degradation: DNA, blood, or saliva degrade over time, lowering accuracy.
- Contamination: Delayed processing heightens contamination risks, affecting integrity.
- Loss or damage: Physical evidence, such as fingerprints or hair, can be mishandled or degraded.
- Legal impacts: Delays may compromise case timelines and weaken courtroom reliability.

Minor delays (0–5 days) have little impact; forensic methods and the chain of custody remain intact. Moderate delays (6–10 days) cause gradual deterioration, with visible degradation and contamination risks, although evidence remains usable. Significant delays (11–20 days or more) seriously harm evidence quality, increasing degradation, trace loss, and forensic errors due to insufficient preparation.

3.4. Evidentiary Type and Trial Outcomes

Table 3 presents the relationship between the type of forensic evidence and final judicial outcomes across the sample.

Table 3 Relationships between types of forensic evidence and outcomes of criminal proceedings.

Evidence Type	Convictions Rate	Acquittal Rate	Dismissal Rate (%)	Key Limitation
Biological (DNA, Blood)	86%	8%	6%	Degradation, contamination
Physical (Weapons, Fingerprints)	70%	15%	15%	Misidentification, improper handling
Digital (Phone, Computer)	65%	20%	15%	Authentication and legal admissibility
Chemical (Toxicology)	75%	10%	15%	Variability in lab accuracy
Documentary (Financial Records)	60%	25%	15%	Disputes over authenticity or misinterpretation

Various forms of evidence influence conviction outcomes differently. Biological evidence (DNA, blood, hair) has a high conviction rate (~85%) because of its reliability in linking suspects to crime scenes; however, procedural errors or

contamination can lead to acquittals (~8%) or dismissals (~7%). Physical evidence (weapons, fingerprints) results in convictions (~70%) but may be challenging for accuracy (~15% acquittals) or dismissed (~15%) due to mishandling. Digital evidence (phone, computer data) is vital in financial and cybercrime cases, with a conviction rate of ~65%, but breaches of confidentiality or data errors can cause acquittals (~20%) or dismissals (~15%). Chemical evidence (toxicology, residues) supports convictions (~75%) in drug and poisoning cases, although inaccurate laboratory results (~10%) or procedural violations (~15%) weaken their impact. Finally, documentary evidence (financial records, contracts) yields a ~60% conviction rate in financial crimes, but questions of authenticity or intent often result in acquittals (~25%) or dismissals (~15%).

These findings confirm that biological evidence remains the most probative type in a trial setting, whereas digital and documentary evidence often faces greater scrutiny owing to challenges in validation and jurisdiction-specific evidentiary thresholds.

4. Discussion

The findings of this study confirm that investigative procedures significantly influence the integrity and legal admissibility of forensic evidence across multiple jurisdictions. The observed variation in evidence quality, trial outcomes, and procedural success highlights the importance of standardized forensic protocols, particularly in environments where evidentiary reliability is essential to ensuring fair judicial outcomes.

4.1. Influence of Investigative Practices on Evidentiary Outcomes

Consistent with Wickenheiser's (2023) concept of proactive crime scene management, this study confirms that the application of advanced forensic methods, when combined with robust evidence handling procedures, enhances the success rate of evidence in court. Specifically, the use of techniques such as DNA profiling, ballistic trajectory modeling, and digital trace analysis yielded high-quality evidence that directly contributed to convictions in homicide and organized crime cases. However, the results also show that early collection alone, without procedural integrity (e.g., a proper chain of custody), was insufficient to guarantee evidentiary success. This contradicts studies that emphasize the timing of evidence collection as the sole determining factor and supports a more nuanced view that prioritizes procedural structure and legal compliance.

4.2. Jurisdictional Discrepancies and Procedural Fragility

The comparative element of this study revealed clear discrepancies in investigative capacity, procedural discipline, and legal safeguards among the United States, Brazil, and South Africa. While U.S. cases generally benefit from stronger institutional support and clearer evidentiary guidelines, Brazilian and South African cases faced more frequent rejections of forensic evidence due to incomplete documentation or methodological inconsistencies. This finding supports previous findings by Masese et al. (2023) and Guimarães et al. (2022), who identified structural limitations in forensic crime scene practices and expert engagement. The implications are particularly relevant in transnational investigations, where the mutual admissibility of forensic evidence may be compromised by procedural divergences and uneven legal infrastructures.

4.3. Emerging Forensic Technologies and AI Integration

Although this study included a preliminary review of emerging technologies such as AI, microbiome analysis, and airborne eDNA, their current legal utility remains limited by procedural ambiguity and judicial caution. For example, while Lee et al. (2021) emphasized the potential of microbiome data for suspect identification, this study revealed its practical underuse, largely due to concerns about standardization and evidentiary validation. Similarly, while AI-assisted digital triage offers substantial efficiency in cybercrime and financial crime investigations, as suggested by Kamble et al. (2024), the lack of clear legal frameworks raises questions about transparency, explainability, and admissibility in adversarial proceedings.

Therefore, references to artificial intelligence must move beyond conceptual endorsement and be grounded in demonstrable forensic utility, accompanied by procedural regulation. Courts, as emphasized by Tiwari (2024), will continue to require verifiable and replicable methods, which underscores the need for forensic tools to meet legal standards of evidence.

4.4. Integrity of Environmental Crimes and Evidence

Although not the central focus of the sample, the study's design allows implications for environmental crimes to be extrapolated. Forensic analysis of environmental crime, such as pollution monitoring, illegal dumping, or ecological damage, often relies on physical and chemical evidence that is time sensitive and prone to degradation. The findings from the toxicological and documentary evidence in this study, particularly regarding the chain of custody and admissibility issues, align with the procedural vulnerabilities frequently encountered in environmental prosecutions. As demonstrated by Tymoshenko et al. (2022), the absence of forensic uniformity in ecological investigations weakens prosecutorial success. This study reinforces the need to develop jurisdictionally adaptable standards for environmental forensic evidence, particularly when criminal thresholds (e.g., ecological harm exceeding legal limits) are at stake.

4.5. Contradictions with Prior Research and New Insights

The study also challenges some prior assumptions in the literature. While Wickenheiser (2023) and others advocate for immediate and rapid forensic response, this study shows that without procedural compliance, early collection alone is insufficient. Furthermore, while Lee et al. (2021) suggest microbiome evidence as an auxiliary tool, the present study found growing support among experts for its potential as a primary identification method, provided that legal admissibility standards evolve accordingly. These contradictions reflect the dynamic state of forensic science and underline the need for continuous re-evaluations of legal assumptions and investigatory best practices.

4.6. Practical Implications and Policy Relevance

The practical implications of these findings are substantial. Investigative agencies must prioritize procedural rigor alongside technological sophistication. Standardized training for forensic examiners, legal oversight of evidence handling, and cross-border harmonization of evidentiary rules are essential reforms. The development of jurisdictionally adaptable forensic protocols, particularly for emerging and environmental crimes, can help bridge the gap between scientific capability and judicial acceptability. Moreover, this study supports the creation of centralized forensic databases and the expansion of expert networks to facilitate peer review and method validation.

4.7. Limitations

While this study provides meaningful insights into the influence of investigative practices on forensic evidence in criminal proceedings, several limitations must be acknowledged. First, the variability in legal standards and forensic investigation protocols across jurisdictions introduced challenges in standardizing the evaluation of evidence integrity and admissibility. Differences in procedural law, admissibility thresholds, and institutional capacity between the United States, Brazil, and South Africa have limited the ability to establish fully comparable benchmarks. This heterogeneity reflects the real-world complexity of transnational criminal investigations but constrains the generalizability of certain findings.

Second, the sample size, although statistically sufficient (n = 120), was unevenly distributed across crime types and jurisdictions. For example, environmental crime cases—although mentioned in the analytical framework—were underrepresented in the dataset, limiting the depth of specific conclusions in that area. Similarly, the number of financial crime cases with complete forensic documentation was lower in some jurisdictions, potentially skewing comparative interpretations.

Third, the study relied on publicly accessible case records, court rulings, and expert interviews, which may not fully capture sensitive procedural errors or internal investigative decisions. Access to sealed case files or confidential procedural documentation would likely have revealed further nuances in the treatment of forensic evidence.

Fourth, while artificial intelligence (AI) has been identified as a promising area for forensic enhancement, this study did not systematically test or implement AI tools. As such, conclusions regarding the role of AI remain conceptual and should be interpreted as exploratory rather than empirical.

Finally, the methodology focused predominantly on postinvestigation outcomes, such as trial success and evidentiary acceptance, rather than real-time investigatory decision-making. Future research incorporating longitudinal observational methods could yield more dynamic insights into how evidence is shaped throughout the entire lifecycle of a criminal case.

4.8. Recommendations

On the basis of the findings and identified limitations, the following recommendations are proposed for policymakers, legal practitioners, and forensic institutions:

Harmonize forensic evidence standards across jurisdictions. The development of regionally or internationally accepted protocols for evidence collection, storage, and admissibility—especially in digital and environmental crime cases—would enhance mutual legal cooperation and improve prosecutorial outcomes. This should include standardized definitions for the chain of custody and admissibility tests.

Specialized training programs for investigators and forensic personnel should be established, focused not only on scientific techniques but also on procedural laws. Cross-disciplinary modules integrating legal, forensic, and ethical components should be incorporated into standard law enforcement education to minimize evidentiary rejection due to technical errors.

Investing in the implementation and legal validation of AI tools in forensic contexts. Policymakers should fund pilot programs to evaluate the effectiveness of machine learning in evidence sorting, trace analysis, and digital forensics, with parallel development of regulations addressing transparency, explainability, and data privacy.

Centralized forensic evidence databases and knowledge-sharing networks are created, allowing for the replication, peer review, and validation of forensic methodologies across borders. This would be particularly beneficial in environmental and cybercrime contexts, where new types of evidence and cross-jurisdictional cooperation are essential.

Research on the forensic investigation of environmental crimes should be supported, emphasizing the collection, preservation, and legal treatment of ecological evidence (e.g., soil, air, and water pollutants). Legal reforms may be necessary to recognize specific forensic categories within environmental criminal law and to strengthen their evidentiary weight in court.

The judicial and legislative review of emerging forensic technologies, particularly microbiome analysis, eDNA, and portable XRF tools, should be encouraged to ensure that innovations meet evolving standards of legal admissibility and procedural fairness.

5. Conclusions

This study confirms that the investigative process plays an important role in the nature, reliability, and admissibility of evidence in a criminal trial. The results support a discernible link between adherence to state-of-the-art forensic techniques and procedure integrity—maintaining an intact custody chain—to evidential success in court. In particular, 85% of the cases where evidence was collected and managed under accepted forensic standards were found guilty, whereas only 52% where procedures were administered randomly.

These findings confirm the anticipation that forensic evidence performance is not dependent on either crime type or the type of science employed, but rather on the extent to which investigative methods comply with procedure and legal standards. Homicide and violent crime cases, often under tighter investigative examination, showed the highest levels of proof success. In contrast, electronic and documentary evidence, which is common in financial and cybercrime cases, was more challenging in terms of authentication, preservation, or adherence to procedures.

While the study was not confined to a single jurisdiction, the cross-national sample reveals substantial disparities in forensic infrastructure and legal standards. These differences underscore the need for harmonized procedural frameworks, especially when faced with transnational crime or mutual recognition of evidence across legal systems. This concern is most relevant in the emerging field of environmental criminal law, where evidence is circumstantial, time sensitive, and collected under field conditions that increase the risk of degradation or procedural error.

The practical significance of this study in the real world is that it demonstrates how scientific integrity and legal compliance together underpin sound investigative practice and how such practice immediately benefits the fairness and effectiveness of the criminal justice system. High-quality forensic evidence increases the reliability of judicial decisions, protects defendants' and victims' rights, and ensures public trust in the judiciary.

In the future, the infusion of artificial intelligence and other cutting-edge technologies into forensic work holds great promise for enhancing both efficiency and evidentiary accuracy. However, without corresponding legal supervision and standardization, these technologies threaten to create more procedural headaches than help does. Future studies should thus focus on the formulation of legal regimes for applying AI in evidence analysis, as well as more in-depth empirical research in environmental forensics, especially where ecological harm crosses over into criminal liability. Finally, this study calls for a more law-oriented and multidisciplinary approach to forensic examination—one that not only recognizes scientific advancement but also guarantees that procedural safeguards avoid abuse to further the cause of justice administered fairly, openly, and without arbitrariness.

Ethical considerations

Not applicable.

Conflict of interest

The authors declare that they have no conflicts of interest.

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