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A Comprehensive review on the uses of Botanical Trace Evidences in Forensic Investigations

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Abstract

Forensic botany has emerged as a pivotal tool within the realm of forensic science, leveraging botanical trace evidence – pollen, leaves, wood, and spores – to unravel criminal investigations. This review synthesizes diverse studies, emphasizing the significance of botanical evidence in criminal inquiries, its varied applications, challenges, and potential prospects. Literature highlights the broad spectrum of botanical evidence applications in forensic investigations, showcasing disciplines like palynology, wood analysis, leaf morphology, and plant molecular biology. Leaves, wood, and pollen play vital roles in plant species identification, providing locational evidence, indicating seasonal aspects, and serving as crucial trace evidence. Forensic palynology stands out as a key discipline decoding concealed insights within pollen and spores, offering insights into crime scene locales, suspect movements, and temporal contexts. The abstract underscores the intrinsic characteristics of pollen for identification, emphasizing their microscopic nature, taxonomy-based identification, and durability.Despite botanical evidence's importance; challenges persist, requiring specialized expertise for analysis and interpretation. However, disciplines like forensic palynology and wood analysis significantly contribute to resolving criminal cases.Advocating for continued advancements and collaborative efforts among forensic scientists, this article concludes by stressing the integration of cutting-edge techniques to enhance the efficacy of botanical trace evidence in forensic investigations. Its utilization holds immense promise for the future of forensic science, advancing the pursuit of justice.

Keywords: Forensic Botany, Palynology, Crime scene investigation, Trace evidence analysis, Forensic science advancements etc.

1. Introduction

Forensic science, an intricate amalgamation of disciplines aimed at unraveling crimes, has undergone significant evolution. Within this expansive realm, forensic botany has emerged as a promising tool, harnessing plant-related evidence to unlock mysteries and provide vital insights into criminal investigations. This exhaustive review aims to delve into the multifaceted domain of botanical trace evidence, shedding light on its pivotal role in the forensic landscape. Plants, fundamental to our ecosystem and sustenance, possess a dual nature within the context of crime. While the majority of plant species offer immense benefits, specific plants have become entwined with illicit activities, spawning various negative consequences. The misuse of plants like cannabis, opium, and coca has resulted not only in drug-related issues but also in connections to organized crime and violence. This intricate interplay between botanical elements and criminal activities underscores the complexities involved (National Geographic Society, 2020; Xiong et al., 2021). The significance of plants in forensic investigations extends beyond their involvement in criminal activities. Plant materials recovered from crime scenes—such as pollen, seeds, and fragments—stand as silent yet compelling witnesses, providing crucial insights into the timing, location, movement of suspects, and connections to criminal acts. However, the misuse of certain plants in criminal contexts should not overshadow their myriad benefits. A balanced perspective should guide our understanding, acknowledging both the positives and negatives, while advocating for measures aimed at curbing the adverse impacts of plant misuse through education, prevention, and law enforcement (UNODC (United Nations Office on Drugs and Crime), 2019) This review aims to explore the vast potential of plant-related evidence in forensic science, shedding light on its applications, challenges, and prospects. By amalgamating botanical knowledge with forensic techniques, forensic botany presents a fertile ground for advancing crime-solving methodologies. The convergence of interdisciplinary forensic science with botanical insights fosters a synergy that enriches investigative practices, significantly contributing to the pursuit of justice. Delving into the role of plants in criminal investigations reveals a myriad of possibilities. From identifying plant species at crime scenes to deducing geographic locations through leaf analysis, understanding seasonal indicators, and utilizing pollen analysis for tracing origins or suspect movements—each avenue offers a unique opportunity to augment forensic methodologies. Moreover, the burgeoning field of forensic palynology, focused on the study of pollen and spores, stands as a testament to the microscopic yet robust nature of botanical evidence, providing invaluable insights in forensics (Raje et al., 2022; Stephen, 2014). Despite botanical evidence's historical instrumental role in solving crimes, its full potential remains underexploited. As forensic botany continues to evolve, integrating advancements from research laboratories and aligning with legal frameworks, it holds promise not only in criminal investigations but also in areas such as national security and historical inquiries (Hoch, 2009; Kruglak et al., 2019).

This comprehensive review seeks to encapsulate the breadth and depth of botanical trace evidence in forensic investigations, scrutinizing its botanical and forensic aspects. From plant anatomy to the validation of botanical evidence in the judicial system, this exploration aims to delineate the nuances, challenges, and prospects within the domain of forensic botany.

2. Literature Studies

Wiedenhoeft et al., 2019 shed light on challenges related to fraud and misrepresentation in the retail forest products industry. Emphasized the inadequacy of current forensic wood science resources and technologies in detecting fraudulent practices. Urged for increased investment in advanced forensic analysis methods for sustainable forest management.

Reis et al., 2019 explored the potential of palynology in forensic investigations, studying soil samples from various locations in Portugal. Demonstrated the utility of palynological analysis in providing information about crime locations, time periods, and potentially identifying suspects or victims.

Sharma, 2020 explored leaf morphology and anatomy's role in forensic investigations. Emphasized botanical evidence's significance in forensic science, focusing on plant species identification methods and their application in crime scene analysis.

Chen & Shi, 2020 provided an informative review of forensic palynology's progress and its diverse applications in forensic science. Summarized techniques used for analyzing pollen and spores from crime scenes, highlighting their potential contributions to criminal investigations.

Alotaibi, 2020 offered an exhaustive overview of the potential applications of pollen molecular biology in forensic palynology. Explored pollen identification methods, such as microscopy, pollen DNA barcoding, and metabarcoding, and discussed their advantages and limitations.

Ishak et al., 2021 offered a comprehensive overview of microbiome utilization in forensic botany. Explored various microbiome analysis techniques and their applications in identifying plant materials, linking them to crime scenes or suspects, and detecting plant-based toxins.

Shugar et al., 2021 presented studies utilizing X-ray fluorescence (XRF) and neural network machine learning for rapid wood species identification. Demonstrated the effectiveness of XRF analysis in identifying wood elemental compositions and its potential in forestry and wood processing industries.

Kitin et al., 2021 explored the application of direct analysis in real-time mass spectrometry for analyzing chemical signatures of Afzelia wood species. Highlighted the method's potential in identifying and managing rare or endangered tree species.

Jadhav et al., 2022 provided a comprehensive review on the collection and analysis of botanical evidence in forensic investigations. Explored various botanical evidence types, techniques for their collection/preservation, and their role in real-life criminal investigations.

Siegel &Mirakovits, 2021 offered a comprehensive overview of pollen and spore analysis, along with entomology, in forensic science. Discussed their roles in identifying crime scenes, determining time of death, and tracing the origin of drugs and poisons.

Kasprzyk, 2023 explored the emerging field of forensic botany, focusing on the various ways plant material serves as crucial evidence in criminal investigations. Addressed developmental areas and knowledge gaps within forensic botany research.

Roncato et al., 2023 explored forensic reconstructive hematology's applications in Brazil, emphasizing its role in identifying human remains, determining the cause of death, and reconstructing crime scenes.

GONCALVES et al., 2023 detailed a protocol for recovering pollen grains from body surfaces and materials in natural environments. Demonstrated the importance of pollen analysis in forensic investigations, particularly in cases involving suffocation, drowning, or burial.

Table: Summarizes various research article in the field of forensic botanical science and their respective profiles, objectives, and conclusions.

Author's Profile	Objective of the Paper	Conclusion
Wiedenhoeftet.al., 2019	Challenges in forensic wood science and retail forest product industry	Insufficient technology to counter fraud; investment in advanced methods needed for sustainable practices.
Reis et. al., 2019	Potential of palynology in forensic investigations	Palynology helps in crime-related location, time, suspect/victim identification.
Alotaibi et al., 2020	Applications of pollen molecular biology in forensic palynology	Different methods (microscopy, DNA barcoding) complement each other in pollen identification.
Chen et. al., 2020	Progress in forensic palynology and its applications	Forensic palynology assists in determining time/location of death and suspect identification.
Sharma et.al., 2020	Explore leaf morphology & anatomy in forensic investigations	Botanical evidence, specifically leaf morphology & anatomy, is valuable in crime scene analysis.
Ishak et. al., 2021	Overview of microbiomes in forensic botany	Microbiome analysis aids in identifying plant materials, their origins, and detecting plant-based toxins.
Kitinet.al., 2021	Use of DART TOFMS for chemical analysis of wood	DART TOFMS effectively distinguishes wood types, potential for managing rare/endangered species.
Shugaret.al., 2021	XRF & machine learning for rapid wood species identification	Effective wood species classification using XRF coupled with neural network machine learning.
Jadhavet.al., 2022	Comprehensive review on	Various botanical evidence types (leaves,

	collection & analysis of botanical evidence	flowers, etc.) can provide critical insights in investigations.
Siegel et.al., 2021	Application of pollen, spore analysis, and entomology in forensic science	Pollen/spore analysis aids in crime scene identification and entomology in estimating time of death.
Goncalveset. al., 2023	Protocol for recovering pollen grains in forensic investigations	Pollen analysis from bodies aids in suffocation/drowning cases; valuable forensic tool.
Roncatoet.al., 2023	Forensic reconstructive hematology and its applications	Forensic hematology assists in identification, cause of death, and crime scene reconstruction.
Kasprzyk'set.al., 2023	Emerging field of forensic botany and its applications	Plant material utilization in solving crimes requires further research for optimal application.

3. Plants as Trace Evidence

Forensic botany is a sub discipline of forensics that is still, perhaps, in its infancy. It is, however, becoming a more common tool as law enforcement agencies, forensic scientists, and attorneys become more familiar with the applications of plant material to casework (Hoch, 2009). Also, as plant research continues in academic and private research laboratories, new tools are being developed that can be eventually applied to forensic botanical evidence to aid in criminal and civil cases (Kruglak et al., 2019). In addition, these new tools can be important for national security and historical issues. Plant evidence is commonly associated with crime scenes and victims; typically, stems, leaves, seeds, flowers, and other identifiable parts of plants are useful as trace botanicals (D. W. ,& B. J. Hall, 2012; D. W. Hall & Byrd, 2012). One might imagine that the chemical composition of herbs, spices, condiments, beverages, fibres, medicines, plant resins, and oils, for example, may be useful for forensically relevant plant "signature" programs just as those used in drug chemistry (e.g., cocaine, heroin) if appropriate databases can be constructed (D. W. ,& B. J. Hall, 2012; D. W. Hall & Byrd, 2012).

4. Pollens as trace evidence

Forensic botany collective application of many disciplines and results ultimately in their application to matters of law. The botanical aspects of forensic botany include plant anatomy, plant growth and behaviour, plant reproductive cycles and population dynamics, and plant classification schemes (morphological and genetic) for species identification (Coyle et al., 2012). The forensic aspects require an understanding of what is necessary for botanical evidence to be accepted as evidence in our judicial system. Forensics requires recognition of pertinent evidence at a crime scene, appropriate collection and preservation of evidentiary material, maintenance of a chain of custody, an understanding of scientific testing methods, validation of new forensic techniques, and admissibility criteria for court (D'Anna et al., 2023).

5. Evidentiary value of Leaves

Table: Provides a concise breakdown of the various roles and significance of leaves in forensic investigations across different aspects (Kasprzyk, 2023).

Aspect	Description
Plant Identification	Analysis of leaf morphology, venation patterns, and other characteristics by botanists or forensic experts aids in determining the specific plant species present at a crime scene or associated with evidence.
Locational Evidence	Presence of specific plant leaves in a geographic area provides insights into potential crime locations or origins of evidence, aiding investigators in inferring movement or item origins.
Seasonal Indicators	Examination of leaf condition, growth stage, color, shape, size, presence of buds, or flowers helps forensic experts estimate the approximate timing of a crime incident.
Pollen Analysis	Investigation of pollen grains on leaves reveals information about geographic origin, suspect or victim presence, movement patterns, or locations where the leaves were collected.
Trace Evidence	Leaves may harbor trace materials like fibers, hairs, or DNA samples from perpetrators, victims, or the environment. Analysis of these elements offers potential leads in investigations.

6. Evidentiary value of wood

Wood serves a pivotal yet confined role in forensic investigations, primarily employed in three domains: the physical alignment of fractured fragments, as a foundation for toolmarks, and as minute trace evidence. Profound knowledge of wood anatomy proves invaluable in analysis, exemplified in the Lindbergh kidnapping case where Arthur Koehler meticulously tracked the wooden ladder, leveraging his expertise in wood technology (Tishman, 2017). Forensic wood examinations commonly entail discerning small wood remnants or sawdust, hinging on precise identification of questioned and known samples. Microscopic identification necessitates precise sectioning of specimens along transverse, radial, and tangential orientations, unveiling distinct attributes indispensable for identification (Wang et al., 2013).

The correct orientation of wood particles is pivotal since cross-sections unveil distinct morphological traits, differentiating woods based on their anatomical characteristics (Desch, 2016). Microscopical examination requires meticulous preparation involving sectioning under a stereomicroscope, mounting sections on slides using glycerin-alcohol, and subsequent air removal through boiling (Von Arx et al., 2016). In cases where particles like sawdust are too diminutive to section, direct microscopic observation might yield crucial identification clues (Houck, 2014).

Ensuring the availability of well-documented known samples is paramount for the comparative analysis of wood particles recovered from crime scenes. A dearth of reliable known samples might lead to erroneous associations of questioned wood particles with specific incidents (Ladd, 2015). The identification of woods from minute fragments demands specialized expertise, and the absence of certain diagnostic traits may impede straightforward identifications (Vospernik, 2019). Contemporary computer programs and standardized terminology endorsed by the International Association of Wood Anatomists have supplanted conventional punch cards, assisting microscopists in identifying uncommon or unfamiliar woods (Beaudry, 2006; Cullinan, 2001).

7. Forensic Palynology

Palynology, the study of pollen, spores, and other acid-resistant microscopic plant bodies collectively known as palynomorphs, is an interdisciplinary field with applications in many areas of science, including forensics, geology, geography, botany, zoology, archaeology, and immunology (Stephen, 2014). Many of these areas impact on and overlap with each other and, when combined, form the study of forensic palynology. Like many forensic disciplines today, palynology involves the study of microscopic evidence that is resistant to damage or removal from crime scenes. The value of forensic palynology lies in four important attributes of pollen and spores (Raje et al., 2022).

• They are microscopic in size.

• Pollen and spores are produced in vast numbers.

• Pollen and spores can be identified to a plant taxon.

• They are highly resistant to decay

Therefore, someone who commits a crime may unknowingly take away or leave at a crime scene critical pollen and spore evidence in large numbers and they are too small to be seen. Pollen and spores are so resistant to decay that they will be preserved for many years without specialized storage, and so morphologically complex that they can be identified to a specific plant type, site, region, or country (Murray, 2011). All plants produce either pollen or spores as part of their reproductive cycle. Pollen, the fine yellow dust produced by flowers, is best known for causing hay fever and contributing to asthma (Milne, 2004). These misery-producing microscopic particles are the plant world's equivalent of sperm they carry the male sex cells of the higher vascular plants (flowering and cone-bearing plants). Spores, although similar in size and distribution to pollen, are the asexual reproductive bodies of lower vascular plants (e.g., ferns) and nonvascular plants (e.g., mosses and fungi), and develop into a new organism without the need for joining with another reproductive cell (Pinna, 2017). To effect fertilization, pollen grains generally reach the female parts of a f lower of the same species with the assistance of wind or animal vectors (typically insects) (Dar et al., 2017). As this is a random affair, plants must produce enormous amounts of pollen to ensure that some pollen grains reach their intended destination (the receptive stigma of a flower) (Manetas and Manetas 2012). Most pollen grains are unlucky and end up as components of soil and dust, falling onto any surface exposed to the air (Bryant Jr et al., 1990). The type of pollen present at any one location, or on any object, can often be related to a particular vegetation type, site, or region. It is this aspect that enables the comparison of pollen samples to prove or disprove a relationship between a suspect, victim, and people (such as witnesses), objects, or localities (Mildenhall et al., 2006).

Table: Characteristics of Pollen for Identification(Agashe, 2019; Božič&Šiber, 2020; Brown, 2017; Cantat et al., 2013; Judd et al., 1999; Maruthi& Ramakrishna, 2022; Pacini, 2017; Pullaiah et al., 2019; Saraswati& Srinivasan, 2015; Šaulienė et al., 2019; Smith, 2021; Wiltshire, 2009)

Characteristics	Description	Author's Profile
Size	Ranges from 5 to 200 µm in diameter, with most falling within 20 to 70 µm. Useful for categorization but unreliable for precise species identification due to size variations.	Brown 2017; Pacini et al. 2017; Judd et al. 2016; Šaulienė et al. 2019
Shape	Diverse shapes - spherical, triangular, elliptical, etc. Variations in ratios of polar and equatorial diameters. Valuable for general categorization but insufficient for species identification.	Cantat et al. 2013; Božič and Šiber 2020
Aperture Type	Most grains have openings (apertures) for male gametes. Types include pores, colpi, or rupturing walls. Useful for distinguishing between genera and species.	Pullaiah et al. 2019; Smith 2021
Sculpture	Surface ornamentation - simple to ornate patterns. Consistent within a species. Patterns include granulate, echinate, verrucate, baculate, or reticulate.	Agashe 2019
Wall Composition & Preservation	Walls consist of cellulose, protein, sporopollenin. Best preserved in anaerobic, acidic conditions. Resistance to degradation aids in forensic evidence retention.	Maruthi et al. 2022; Saraswati et al. 2015; Wiltshire 2009

A single palynology sample derived from diverse sources typically encompasses a rich array of pollen, spore types, and an assortment of microscopic plant materials. This collective identification of pollen and spores within a sample is termed a "pollen assemblage" or palynomorph assemblage. In terrestrial environments, samples can comprise not only pollen and spores but also fern and moss spores, fungal spores, plant cuticles, wood fragments, fibers, tracheids, phytoliths (silica crystals produced by most plants), occasional fragments of charcoal, and remnants of insect remains. The amalgamation of these microscopic particles holds substantial significance for the comparative analysis of forensic pollen assemblages (Mildenhall et al., 2006).

Samples obtained from or in proximity to aquatic sources often harbor characteristic pollen and spores associated with that specific environment. Remarkably, even tap water may contain traces of pollen and spores. Water samples might additionally contain indicators indicative of localities or environmental settings. Non-pollen and spore indicators encompass microorganism cysts from dinoflagellates, as well as diatoms, minute single-celled algae producing a siliceous skeleton (Zolitschka, 2015). Within marine environments, the calcareous remnants of microscopic protozoans known as foraminifera can be present in untreated samples. While the chitinous organic lining of these small creatures can endure chemical pollen preparation, their presence in a processed sample serves as exceptional environmental markers (Pye, 2007).

8. Conclusion

Botanical evidence stands as a cornerstone in forensic science, furnishing crucial insights to investigators and aiding in the resolution of crimes. The applications of forensic palynology and forensic wood analysis emerge as particularly invaluable, each method offering distinctive advantages in unraveling the origins of evidence and the circumstances surrounding criminal acts.Forensic palynology emerges as a pivotal tool enabling the identification of pollen and spores discovered on individuals or objects, offering pivotal clues regarding crime scene locations or suspect movements. Through meticulous examination of pollen and spores, forensic palynologists decipher the seasonality and environmental context of the evidence, furnishing investigators with pivotal contextual information. Moreover, this discipline serves to link suspects to specific areas, proving instrumental in investigating crimes such as arson, drug trafficking, and smuggling.On the other hand, forensic wood analysis provides a unique perspective on evidence origins, disclosing insights into the wood's type, age, and geographical provenance. This information acts as a crucial link between suspects and specific locations, aiding in identifying the source of evidence, including weapons or tools used in crimes.However, the utilization of botanical evidence in forensic inquiries presents challenges. The complex and time-consuming analysis of pollen and spores demands specialized expertise for result interpretation. Similarly, the meticulous preparation and analysis of wood samples necessitate trained experts for accurate interpretation.Notwithstanding these challenges, the significance of botanical evidence in forensic inquiries cannot be overstated. The utilization of forensic palynology and forensic wood analysis has significantly contributed to resolving numerous criminal cases. Their relevance in forensic science is poised to expand further in the future. Consequently, ongoing advancements and improvements in these methodologies, coupled with increased collaborations among forensic scientists, law enforcement agencies, and relevant stakeholders, are imperative for their sustained success in the future.

References:

Agashe, S. N. (2019). *Pollen and spores: applications with special emphasis on aerobiology and allergy*. CRC Press.

Alotaibi, S. S. , S. S. M. , A. M. , A. R. , B. A. , A. N. , &Alhamed, R. (2020). Pollen molecular biology: Applications in the forensic palynology and future prospects: A review. *Saudi Journal of Biological Sciences*, *27*(5), 1185–1190.

Beaudry, M. C. (2006). *Findings: the material culture of needlework and sewing*. Yale University Press.

Božič, A., &Šiber, A. (2020). Mechanical design of apertures and the infolding of pollen grain. *Proceedings of the National Academy of Sciences*, *117*(43), 26600–26607.

Brown, T. (2017). Forensic applications of micropalaeontology. In *The Archaeological and Forensic Applications of Microfossils: A Deeper Understanding of Human History* (pp. 245–260). Geological Society of London.

Bryant Jr, V. M., Jones, J. G., &Mildenhall, D. C. (1990). Forensic palynology in the United States of America. *Palynology*, 193–208.

Cantat, I., Cohen-Addad, S., Elias, F., Graner, F., Höhler, R., Pitois, O., Rouyer, F., & Saint-Jalmes, A. (2013). *Foams: structure and dynamics*. OUP Oxford.

Chen, Y. X., & Shi, H. F. (2020). Research Progress on Forensic Palynology and Its Application in Forensic Science. *Fa Yi XueZaZhi*, *36*(3), 354–359.

Coyle, H. M., Massey, P., & Valentin, P. (2012). Forensic botany. *Forensic Ecology Handbook*, 169–181.

Cullinan, P. ,& M. S. (2001). Wood Science and Technology. *Irish Forestry*, *58*(1/2), 81–91.

D'Anna, T., Puntarello, M., Cannella, G., Scalzo, G., Buscemi, R., Zerbo, S., & Argo, A. (2023). The Chain of Custody in the Era of Modern Forensics: From the Classic Procedures for Gathering Evidence to the New Challenges Related to Digital Data. *Healthcare*, *11*(5), 634.

Dar, S. A., Hassan, G. I., Padder, B. A., Wani, A. R., &Parey, S. H. (2017). Pollination and evolution of plant and insect interaction. *Journal of Pharmacognosy and Phytochemistry*, *6*(3), 304–311.

Desch, H. E. ,&Dinwoodie, J. M. J. M. (2016). Timber: structure, properties, conversion and use. *Bloomsbury Publishing*.

GONCALVES, A. B., de França Alves, R., de Miranda Chaves, S. A., Pott, A., Reinhard, K. J., da Silva Santos, K. C. B., de Oliveira, W. R., &Pistori, H. (2023). Natural environment: protocol to recover pollen grains on the bodies. *RevistaBrasileira de Criminalística*, *12*(1), 70–73.

Hall, D. W. ,& B. J. (2012). Plant biotechnology. *Infobase Publishing*.

Hall, D. W., & Byrd, J. (2012). *Forensic botany: a practical guide*. John Wiley & Sons.

Hoch, J. M. (2009). Forensic Botany: A Practical Guide. *John Wiley & Sons.*

Houck, M. M. ,& S. J. A. (2014). *Fundamentals of Forensic Science* (3rd ed.). Elsevier Academic Press.

Ishak, S., Dormontt, E., & Young, J. M. (2021). Microbiomes in forensic botany: a review. *Forensic Science, Medicine and Pathology*, *17*, 297–307.

Jadhav, E. B., Parihar, K., Sankhla, M. S., &Sonone, S. (2022). Collection of Botanical Evidence. *Manual of Crime Scene Investigation*, 119–131.

Judd, W. S., Campbell, C. S., Kellogg, E. A., Stevens, P. F., & Donoghue, M. J. (1999). Plant systematics: a phylogenetic approach. *EcologíaMediterránea*, *25*(2), 215.

Kasprzyk, I. (2023). Forensic botany: who?, how?, where?, when? *Science & Justice*.

Kitin, P., Espinoza, E., Beeckman, H., Abe, H., & McClure, P. J. (2021). Direct analysis in real-time (DART) time-of-flight mass spectrometry (TOFMS) of wood reveals distinct chemical signatures of two species of Afzelia. *Annals of Forest Science*, *78*, 1–14.

Kruglak, K. J., Dubnicka, M., Kammrath, B., Maxwell, V., &Reffner, J. A. (2019). The Evidentiary Significance of Automotive Paint from the Northeast: A Study of Red Paint. *Journal of Forensic Sciences*, *64*(5), 1345–1358. https://doi.org/10.1111/1556-4029.14007

Ladd, C. ,& M. J. (2015). Microscopy of Trace Evidence. In Forensic Microscopy for Skeletal Tissues. *Springer, Cham*, 17–48.

Maruthi, Y. A., & Ramakrishna, S. (2022). Sporopollenin-Invincible biopolymer for sustainable biomedical applications. *International Journal of Biological Macromolecules*.

Mildenhall, D. C., Wiltshire, P. E. J., & Bryant, V. M. (2006). Forensic palynology: why do it and how it works. *Forensic Science International*, *163*(3), 163–172.

Milne, L. A. , B. V. M. , &Mildenhall, D. C. (2004). Forensic palynology. *Forensic Botany: Principles and Applications to Criminal Casework*, 217–252.

Murray, M. & C. J. (2011). Forensic palynology: Why do it and how it works. *Forensic Science International*, *1–3*, 1–8.

National Geographic Society. (2020). The Power of Plants. *National Geographic Magazine*.

Pacini, E. , F. G. G. , and H. M. (2017). The Role of the Tapetum in Pollen Development and Performance, and in the Evolution of Pollen Types. In Pollen Terminology, edited by P.H. Hoen and P.J.M. Maas. *Springer International Publishing, Cham.*, 1–33.

Pinna, D. (2017). *Coping with biological growth on stone heritage objects: methods, products, applications, and perspectives*. CRC Press.

Pullaiah, T., Lakshminarayana, K., & Rao, B. H. (2019). *Plant Reproduction 2nd Ed*. Scientific Publishers.

Pye, K. (2007). *Geological and soil evidence: forensic applications*. CRC press.

Raje, S. C., Bhagat, D. S., Nimbalkar, R. K., Shejul, S. K., Bumbrah, G. S., &Sankhla, M. S. (2022). Contributions and Current Trends of Forensic Botany in Crime Scene Investigation. *Forensic Science Journal*, *21*(1), 1–12.

Reis, C. I. C., Coimbra-Dores, M. J., Rebelo, M. T., &Faria, M. S. (2019). Palynological analysis of soil in Portugal: potential for forensic science. *Palynology*, *43*(4), 585–595.

Roncato, P. A., da Costa Serra, M., & da Silva Fernandes, C. M. (2023). Forensic reconstructive hematology: Analysis and reflections on its development and applications in Brazilian forensic cases. *Seven Editora*.

Saraswati, P. K., & Srinivasan, M. S. (2015). *Micropaleontology: Principles and applications*. Springer.

Šaulienė, I., Šukienė, L., Daunys, G., Valiulis, G., Vaitkevičius, L., Matavulj, P., Brdar, S., Panic, M., Sikoparija, B., & Clot, B. (2019). Automatic pollen recognition with the Rapid-E particle counter: the first-level procedure, experience and next steps. *Atmospheric Measurement Techniques*, *12*(6), 3435–3452.

Sharma, S. , R. S. , &Singla, P. (2020). *FORENSIC ANALYSIS OF LEAF AS A BOTANICAL EVIDENCE*.

Shugar, A. N., Drake, B. L., & Kelley, G. (2021). Rapid identification of wood species using XRF and neural network machine learning. *Scientific Reports*, *11*(1), 17533.

Siegel, J. A., &Mirakovits, K. (2021). Forensic Palynology and Entomology. In *Forensic Science* (pp. 401–422). CRC Press.

Smith, V. (2021). *Palynology and Paleoclimatology of the Chicxulub Impact Crater in the Early Paleogene*. Louisiana State University and Agricultural & Mechanical College.

Stephen, A. (2014). Pollen: A microscopic wonder of plant kingdom. *International Journal of Advanced Research in Biological Sciences*, *1*(9), 45–62.

Tishman, S. (2017). *Slow looking: The art and practice of learning through observation*. Routledge.

UNODC (United Nations Office on Drugs and Crime). (2019). *World Drug Report 2019*.

Von Arx, G., Crivellaro, A., Prendin, A. L., Čufar, K., &Carrer, M. (2016). Quantitative wood anatomy—practical guidelines. *Frontiers in Plant Science*, *7*, 781.

Vospernik, S. ,&Gindl-A. W. (2019). Recent advances in wood identification: from sample preparation to species determination using next-generation sequencing. *Wood Science and Technology*, *53*(4), 753–772.

Wang, Y., Xu, J., Wang, Y., & Chen, H. (2013). Emerging chirality in nanoscience. *Chemical Society Reviews*, *42*(7), 2930–2962.

Wiedenhoeft, A. C., Simeone, J., Smith, A., Parker-Forney, M., Soares, R., & Fishman, A. (2019). Fraud and misrepresentation in retail forest products exceeds US forensic wood science capacity. *PloS One*, *14*(7), e0219917.

Wiltshire, P. E. J. (2009). Forensic ecology, botany, and palynology: some aspects of their role in criminal investigation. In *Criminal and environmental soil forensics* (pp. 129–149). Springer.

Xiong, H., Luo, M., Ju, Y., Zhao, Z., Zhang, M., Xu, R., Ren, Y., Yang, G., & Mei, Z. (2021). Triterpene saponins from Guo-gang-long attenuate collagen-induced arthritis via regulating A20 and inhibiting MAPK pathway. *Journal of Ethnopharmacology*, *269*, 113707. https://doi.org/10.1016/j.jep.2020.113707

Zolitschka, B. , F. P. , O. A. E. , S. A. , &Dechnik, B. (2015). Varved lake sediments. In Tracking Environmental Change Using Lake Sediments. *Springer*, 3–56.