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Contributions and Current Trends of Forensic Botany in Crime Scene Investigation

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Abstract

Forensic botany is the field of science that applies the knowledge, techniques, and study of plant science to legal matters. The term forensic botany proves that plants can provide forensic evidence, as various plant species occur in the environment, which is limited to specific geographic locations. Besides, every species has unique characteristics. Hence, these features make plants be useful evidence for solving criminal and civil cases. However, forensic botany remains an underutilized field in forensic casework. Furthermore, although most forensic scientists are familiar with methods for human identity testing, the use of the plant, animal, and insect evidence is yet unknown. This low knowledge is due to a lack of awareness by evidence collection teams, who do not necessarily know the importance of collecting botanical trace evidence. Therefore, this review article encompasses different sub-disciplines that come under forensic botany along with case reports and proper collection procedures of botanical evidence. Overall, this article gives the importance and applications of botanical evidence during criminal and civil case investigations.

Keywords: forensic botany, botanical evidence, crime scene investigation

Introduction

The law of circumstances states that "Facts do not lie, but man can do." This law proves that every piece of evidence is important and useful while investigating a sequence of events. It also indicates that oral testimony can be influenced or changed, but the result of physical evidence along with other corroborative evidence cannot be changed, which makes a sequence of the event clear. Therefore, it is necessary to carefully collect every piece of evidence and preserve it properly. Similarly, the omnipresence of botanical evidence on the crime scene enhances its usefulness in solving criminal cases. Therefore, forensic botany is the field of science that

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applies the knowledge, techniques, and study of plant science to legal matters [1].

Botanical trace evidence can be used for different purposes, such as establishing links between suspects, victims, crime scenes, and objects. This link was established by comparing those botanical pieces of evidence obtained from suspects with botanical evidence found at the crime scene [2]. However, using forensic botany is limited in criminal or civil cases because a diminutive number of forensic scientists are trained for this field through academic learning [3]. Also, although most forensic scientists are familiar with methods for human identity testing, the evidence from plants, animals, and insects remains unknown. This scarcity in knowledge is due to the lack of awareness by evidence collection teams, who are unaware of the value of collecting botanical trace evidence [4].

Scientists who studied in academic institutions have received training in one or more special aspects of plant science, such as anatomy, genetics, morphology, systematics, taxonomy, plant ecology, palynology, algology, diatomology, and so on, nonetheless, they frequently are untrained in forensic science. Hence, it becomes the task of the investigator to inform the plant scientist of standard forensic procedures, including how to handle evidence, how to handle the crime scene, and related matters until they are familiar with the routine [5]. Still, this field remains an underutilized field of investigation, with its most common application being limited to identifying plant species, including suspected illegal plants.

Plants as Botanical Evidence

Plants can provide forensic evidence because of their body's components and structural make-up, including its ecological requirements, which are particular to specific species [6]. Botanical materials can therefore be useful in forensic analyses of rape cases, burglaries, kidnapping, and plant poisoning cases. Plants can also be useful for determining whether the death was due to an accident, suicide, or homicide, as well as what time of the year burial was proposed to have taken place [7]. Additionally, it helps determine primary or secondary scenes, locate missing bodies, determine time and cause of death through the analysis of gastrointestinal contents, and track drug distribution networks in which plant species were involved [8]. Alternatively, wood identification and comparisons can help identify a suspect involved in illegal logging, whereas fungi may help in locating buried corpses. Plant fragments lodged in a shoe associated with the cloth of a victim can also provide clues to a specific location [9]. Likewise, pollen grains of different species can help determine the time and location of a crime, thereby linking suspects to crime scenes [10]. Botanical evidence is also encountered in wildlife cases where endangered or forbidden plants, or products derived from these plants, were collected or traded [11].

Collection, Handling, and Preservation of Botanical Evidence

Management of a crime is the process of performing accurate and effective collection and preservation of evidence [12]. The whole plant itself is not the transgressor, but is used as an evidence against the perpetrator of a crime [13]. Various types of botanical evidence are present on the crime scene. For example, pollen grains and spores, seeds, leaves, flowers, wood, and the stem of a plant or tree, the root of a plant or tree, bryophytes or mosses, lichens, different fungi, diatoms in underwater crime scenes, fruit, the bark of a stem or wood, etc., all serve as evidence [14].

Likewise, botanical evidence can microscopically be present in the crime scene, in which careful collection, documentation, and preservation of these critically influence the evaluation of botanical evidence [15]. The correct and proper identification of botanical evidence also depends on the training of botanists, including their abilities to gain access to recorded information on the characteristics of the species to which the sample belongs. Unfortunately, sometimes samples are collected by untrained personnel or police officers. Therefore, guidelines should state that plant materials need to be collected along with a control sample [16]. Also, before collecting botanical evidence, the color and shape of plants and leaves, along with physical attributes of the botanic material should be noted and photographed [17].

Botanical evidence can be preserved by pressing the plant material between a newspaper or catalog and allowing it to dry naturally. This method retains all the morphological characteristics of the plant. Additionally, for collection and handling of botanical materials, paper or plastic bags in addition to cardboard boxes or airtight containers are used, as they help in storing and drying botanical evidence. The storage bag or

containers that would be used depends on the type and nature of the botanical evidence [18]. Moreover, while preserving evidence, forensic scientists should ensure optimal temperature because many botanical pieces of evidence can be degraded due to high temperature, humidity, or moisture [19]. Botanical samples exposed to heat and higher temperatures, including other adverse climatic conditions, also decompose or degrade within two to three days due to fungal or bacterial actions. Alternatively, before collecting fungi, it should be photographed from different angles such that it includes its physical properties like its shape, color, and size. Then, the evidence is collected in paper bags or packed into pasteboard boxes. Furthermore, during preservation, fungi should be dried properly, which helps these microbes to lose their color, thereby making their morphological characteristics more distinct [13].

Other evidence, such as pollen grains, can be recovered from various sources, including victims' and offenders' clothes, as well as from their hair, respiratory tracts, vehicle tires, air filters in cars, surrounding objects, and muds [20]. Therefore, when pollen grain evidence is suspected to be present in the crime scene, palynologists should be given access to the area first before pollen information is unintentionally altered, removed, or contaminated by the action of other forensic and crime scene investigators [21]. Control samples are samples of surface dirt containing this pollen evidence and spores, including dust, fibers, soot, minerals, or other materials at, near, or directly associated with a crime scene. Thus, a pinch of the control sample should be collected and placed into a sterile container, and the location of the sampled area noted along with the time sample collection occurred [22]. The collected samples can then be stored in contamination-proof containers that are marked, and later placed in cold storage at approximately 0°C to prevent microbial damage of pollen grains in the sample. Subsequently, the botanical evidence is separated using techniques, such as hot surfactant solution, sieving, and centrifugation for further analysis.

Likewise, pollen samples from paving materials (for example artificial stone, tiles, bricks, wood, concrete slab, etc) can be collected using various methods. Tape lifting methods include Transparent taping, Lint rollers and Electrical tapes; swabbing methods include sterile water-soaked cotton swabbing and dust remover-soaked cotton swabbing. If required, these samples can then be preserved in paper or plastic bags as well, in addition to cardboard boxes or airtight containers after proper drying [23].

Disciplines of Forensic Botany

Different sub-disciplines exist, which come under forensic botany. They include; palynology (the study of pollen and spores), plant anatomy, which includes leaf morphology (the study of leaf), dendrochronology (the study of growth rings of tree stems, wood, and roots), bryology (the study of bryophytes), plant ecology (the study of the growth pattern of vegetations), limnology (the study of freshwater plants), and plant systematics (the study of evolutionary relationships between plant species and taxonomy for the analysis of plant species) [24]. The details presented have forensic significance [25]. This article also gives information about various sub-disciplines of forensic botany, along with case studies that are explained briefly. The various disciplines in forensic botany are given in Fig. 1.

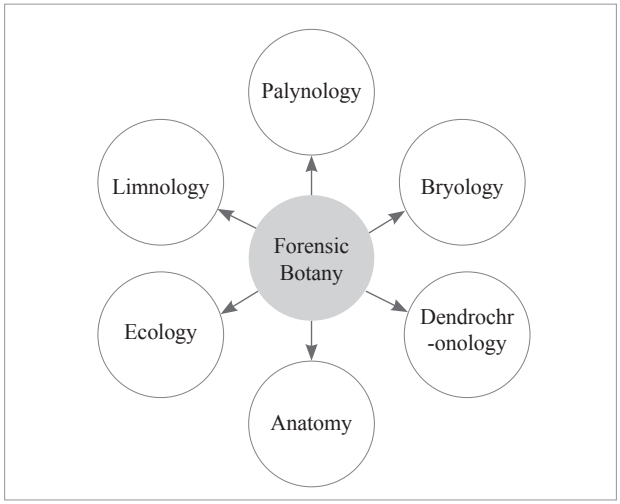

Fig. 1 Disciplines of Forensic Botany

Palynology

Palynology is the study of pollen grain and spores. Forensic palynology is the study of modern and fossil spores or pollens, and use them as one of the evidence in the investigation of crimes. The pollen grain possesses morphological and genetic information help to specify the geographical location [26]. Also, their high abundance, persistence, identifiability, dispersal mechanisms, plenitude and stability to mechanical and chemical destruction, morphology, and the microscopic size of pollen and spores, make them a well-established

research tool in many scientific developments. Notably, forensic palynology has become consistently accepted, and its use has become court-tested in some countries [27]. Whereas, in other countries, neither is occurring at present. Below are the significant applications of forensic palynology [27].

1. It helps relate to items and materials left at crime scenes, which can link a scene to a suspect.
2. It relates a suspect to the crime scene or discovery scene.
3. It relates material or evidence in the disclosure scene to the crime scene.
4. It helps demonstrate or discredit conceivable explanations.
5. It narrows down the list of possible suspects.
6. It helps determine the movement history of drugs.
7. It provides data related to the origin of materials found in the crime scene.
8. It effectively proves or disproves alibis.
9. It gives information as to the geographic location of items.
10. It helps the police in solving their questions.
11. It helps find surreptitious graves and human remains.

A forensic palynologist follows Lockard's exchange principle, which states that "whenever two objects come in contact, there is always a transfer of material" that will give a pollen fingerprint. Therefore, the first task of the forensic palynologist is to try finding a match between the pollen in a forensic sample and that from a known geographical region. Palynologists should have the knowledge of pollen dispersal, developmental responses, and phenology, which influences solving of case problems [28-30]. Palynology also involves the study and identification of many classes of microscopic bodies, the most important being pollen, plant spores, and fungal spores. Conifers and flowering plants produce pollen grains; whereas mosses and ferns produce plant spores, alternatively, their allies and fungi produce different kinds of spores [31].

The cell of pollen itself can lose all viability, which is a large, randomly, cross-linked molecule containing a carbon: hydrogen: oxygen ratio of 4:6:1 [32]. Although its exine is composed of cellulose, different types of proteins, and lipids, pollen walls have interlocking coils and strands of the highly durable material known as sporopollenin, which is among the most chemically stable inert biological polymer. This polymer can protect pollen and spores from external damages, such as rain, high temperature, and chemicals present in the soil. Also, it helps preserve all pollen properties as well as DNA, which is the main component of pollens for up to many years. Due to these characteristics, pollen and spores became essential evidence in crime investigations [33]. Here, cases reporting where pollen and spores played an important role and acted as the main evidence are presented.

Case 1

This case was reported from New Zealand. A huge quantity of hashish resin was found in the ownership of a suspect arrested in one of New Zealand's port cities. A chemical test of the various resin samples revealed a composition unlike the hashish generally recovered by law enforcement agents. Therefore, questions were raised about whether the new hashish samples reflected a new importation type from a possible new foreign source, or it was a new type of hashish being produced somewhere in New Zealand. Subsequently, three samples from the seized hashish were sent to a New Zealand forensic palynologist for examination, which revealed a pollen assemblage linking them to a production region in tropical Southeast Asia or Indomalaya. Findings also showed that all three samples came from the same imported "block" of hashish and that none of it had come from plants grown in the New Zealand area [32].

Case 2

A young woman was claimed to have been raped at night in a wooded strip of land 120 m away from her home. The suspect refused her claim, saying that they had consensual sexual relations on an area of short turf in a local park, 130 m away from the alleged crime scene. Samples from each place, and clothing, and footwear from each party were collected for assessment and analysis. All places relevant to the case were also visited and investigated. Lists of plant species were made as well. Results showed that palynological and mycological profiles produced by the footwear and clothing of both parties were closely related to the wooded area but were dissimilar to that of the park. Further analysis of comparator samples and exhibits also showed that the palynological profiles collected from the clothing and shoes of both parties resembled the profiles of the woodland more than those from the park. Hence, the

palynological evidence strongly supported the woman's hypothesis over that of the suspect. It was, therefore, more expected to be believed that the girl's testimony was more valid than that of the defendant. Afterward, the defendant confessed that he had lain with the girl in the wooded area as she had claimed [30].

Bryology

Bryology is the study of bryophytes, including mosses, liverworts, and hornworts [34]. Forensic bryology in the field involving the study of bryophytes in criminal investigation and legal matters. Bryophytes show their special characteristics in that they are ubiquitous in the field. They are also small, and their fragments suitably remain in the soil, dirt, and debris. Therefore, they easily get attached to shoes, clothes, or vehicles. Bryophyte species show wide distributions, as they help in narrowing a location or itinerary. Additionally, the microscopic fragments of bryophytes are useful since ordinarily, this scale is then used for identification by specialists, as a tiny moss leaf of less than a millimeter long is sufficient for accurate identification. Their ability to survive irregular periods of dehydration or adverse conditions, including their resistance to decay and unacceptability to most herbivores make bryophyte DNA easily extracted and studied [35]. Bryophytes are clonal. Clonal plant colonies consist of only one genotype, which can be identified using DNA marker techniques. Subsequently, results can be used as a piece of evidence in court when trying to link a suspect to a crime [36]. Generally, the height of the bryophytes plant ranges from cm to meter. These plants grow in the form of mats or patches on the ground, and wood etc. [37]. The growth period of bryophyte species can be determined by examining segments on their stems, which have two growth forms; the sympodial growth form and the monopodial growth form. The sympodial growth form occurs when apical meristems (growing tip) die at the end of the growing season, after which lateral buds continue growing in the next season. Alternatively, the monopodial growth form occurs when apical meristems continue growing up to the whole life of the plant and continue growing from the previous year [38]. Monopodial growth is more regular than sympodial growth, and the annual segments are easier to identify because they are situated in an area where side slings change their dimension and positioning [39].

Case report

S.B. was a Caucasian girl, 22 years old and a student at the faculty of Medicine, University of Siena, Tuscany, Italy. The girl was under drug therapy and psychotherapy because of major depression. Therefore, she was regularly subjected to visits and colloquies at the department of psychiatry of the hospital of Siena. During the last set of interviews, she specifically denied having suicidal intentions. However, during therapy, the girl had a depressed mood. After a few months of therapy, the girl died by suicide by jumping from the townhouse of a shopping mall at the center of Siena. The crime scene was the townhouse of a four-story building, which housed a shopping center. Investigations revealed that the bus station of the city, including the University for Foreigners of the University of Siena and this townhouse, was inaccessible to users. Thus, no eyewitnesses or any evidence were available to give information about what happened at the scene of the crime. During the investigation of the crime area, traces of removed mosses were found on the masonry parapet of the townhouse. Similar mosses were also found under the soles of the victim's shoes. Further investigations by medical examiners revealed the absence of mosses on the floor of the townhouse. Also, the analysis of the walkway and service stairs leading to the townhouse had the presence of mosses. Specifically, some areas between the walkway and service scale showed areas of damage compatible with the trampling. Therefore, a sample of moss was removed from these areas. Collected specimens were then preserved in sterile test tubes. Subsequently, all traces of mosses present on the masonry parapet of the townhouse, including those present under the shoes of the victim were carefully collected and stored in a test tube for further analysis [3].

Afterward, bryologists and plant ecologists of the University of Trieste at the Department of Life Sciences were asked to identify the species of these mosses and compare the samples. Next, botanical materials were sampled, mounted on a slide for analysis, and observed using a stereomicroscope. Dichotomous identification methods were also used to identify sampled materials. From the results, two species were determined: Tortula muralis Hedw and Bryum capillare Hedw. Finally, the presence of removed bryophytes from the shoes of the girl and the parapet of the townhouse, including

the presence of fresh bryophytes on the stairs helped reconstruct the accident. Therefore, it was proposed that the girl had walked up to the service stairs alone, staining her shoes with mosses in the process. Then, she climbed on the parapet of the townhouse and committed suicide. The probability that someone pushed her down during a fight was negligible because if someone had thrown the girl, she would not have put her foot on the parapet, leaving the trace with removed moss.

Limnology

Limnology is the study of freshwater bodies, which especially focuses on the presence of diatoms in crime scene samples and on victims [40]. Aquatic plants, such as algae and diatoms, can be useful to link suspects to a crime scene or establish that drowning occurred in freshwater. However, diatom populations change seasonally in lakes, rivers, and ponds [41]. Diatoms are unicellular and photosynthesizing algae with a siliceous skeleton found in fresh and marine waters and soils, including major moist environments [42]. Diatom is classified based on its shape, color, and pattern. [43]. Living diatoms distribute in approximately all aquatic and damp terrestrial habitats. Many of these diatoms also represent the most abundant and diverse algal class. Besides, various applications of diatoms exist. These applications include the matching of environmental samples with substances or materials that have been in contact with water and the investigation of drowning cases. It also includes locating and linking the area in which an underwater crime occurred [44].

Case report

In 1991, teenage assailants violently attacked two young boys while they were fishing at a suburban pond in Connecticut. The boys were held at knifepoint, bound with duct tape, savagely beaten, then dragged into the pond to drown and die. Subsequently, one of the two boys managed to get free, save himself, and rescue his friend. After many hours of criminal investigations, three suspects were in custody. To link suspects to the crime scene, investigators seized sediment samples and crusted sneakers of both the victims and assailants, then analyzed them for algal and diatom species. Next, microscopic analysis of samples from each pair of sneakers plus reference samples from the pond was conducted. Results showed that the same species were present in obtained samples. Similar distribution patterns of each species were observed as well. Therefore, results supported the position that the samples originated from a common freshwater [4].

Plant Ecology and Plant Systematics

Plant ecology is a sub-discipline of ecology that studies the distribution growth patterns of plants, the effects of environmental factors on the growth of plants, and the interaction between plants and other organisms [45]. Forensic plant ecology includes the use of plant ecology in solving criminal cases by identifying and analyzing plant fragments, then linking them with the scene of the crime. Growth patterns and the vegetative (non-flowering) portion of plants can be useful in estimating the time of death [46].

Examination of plant material fragments also help link individuals with the crime scene. These plant fragments are proposed to be found inside vehicles, underneath the body, in the engine compartment, around the wiper blades, and so on, as identified during the investigation [47]. Plant ecology can be useful in finding the location of clandestine graves [48]. Plant systematics is the study of evolutionary relationships between plant species and taxonomy i.e., plant species identification, which is the first step in analyzing botanical evidence [49]. Species identification of plants can be useful in drug trafficking cases [50]. Currently, various methods are employed to identify marijuana. Cystolith hairs are used to identify marijuana, which are present on the leaves of marijuana. However, the presence of systolic hairs is not crucial for identification because more than 80 plant species exist that contain systolic hairs. The "Duquenois-Levine color test" is a screening test for the presence of marijuana. This test shows a purple color in the chloroform layer for the positive test [51]. Also, species identification can help solve plant poisoning cases for identifying the type of poison and its plant origin [52].

Case report

The case was from southeastern Colorado. The mother of an infant named Jacklyn Funderberg had her jaw broken by her boyfriend. The boyfriend then returned with his ex-wife. Soon, Jacklyn disappeared, and her body was found buried in a shallow grave at the

base of a rocky outcrop on the eastern prairie. A shrub was growing on the outcrop, which is unique to this formation. Fragments of this shrub were also related to that found on the victim's body, including grasses that were found only at the gravesite. Investigators found that the victim was thrown off the top of the outcrop, then buried at the bottom. Investigations pointed to the ex-boyfriend. After examining his vehicle, no type of plant fragment was found, which speculated that the car had recently been thoroughly cleaned. During custody, the boyfriend phoned his ex-wife and asked her to wash some of his clothes and hide a pair of shoes. Based on this information, the investigators used his recorded phone message to obtain a warrant and seized his clothing from his ex-wife's washing machine. After examining his clothes, investigators found that the suspect's clothing was contaminated with pieces of unique shrub growing at the top of the outcrop as well as parts from the low-elevation grasses found near the grave. Hence, after watching all this evidence, the suspect changed his original story and claimed during the trial that they had both planned to jump off the top of the outcrop, but that he had lost his daring when it came to his turn. He then panicked and buried her body to hide all the scenes. Therefore, this indirect plant evidence suggested that he was present at the crime scene or a similar location, thereby forming concrete proof that was part of the trial evidence, which led to a conviction of first-degree murder [53].

Plant anatomy

Plant anatomy is the study of the shape, internal arrangement, and size of plants [54]. Forensic plant anatomy is a field used for identifying species of plants in criminal cases. Each plant has specific patterns of cell types with distinct sizes, shapes, and inclusions. Hence, these characteristics help identify individual food plants in samples obtained from the human digestive tract, as plant cells never lose their identifying characteristics while passing through the human digestive tract [55]. Additionally, plant anatomy uses various features, such as leaf morphology and tree growth ring patterns, of seeds, tree bark, flowers, and so on in species identification and in performing physical matches of evidence, respectively [56]. Studies also indicated that high-quality DNA can be recovered from digested seeds with sufficient yield such as a single tomato seed [57].

Case report

In the early 1980s, a young college graduate working in Denver failed to return home one evening, where she was living with her relatives. Her body was found the next day. Investigations showed that she had her last meal at midday with her boyfriend at a well-known fast-food restaurant known for their burgers containing two all meat patties, lettuce, cheese, special sauce on a sesame seed bun, and fries. However, when the Jefferson County coroner conducted her autopsy, he noted that the stomach contents contained vegetable materials unavailable at this fast-food establishment in those days. Therefore, he contacted forensic botanists to examine slides he had made of the stomach contents to ascertain if they would identify the plant material present. Forensic botanists identified plants that indeed would not have been obtained at that restaurant, indicating that the victim had consumed another meal before she died. On further analysis, forensic botanists found fragments of red cabbage, kidney beans, and onions, none of which were available at that fast-food restaurant in those days. Investigations also revealed that although the boyfriend had no alibi in the afternoon, he did have one for the rest of the day. So, he was removed as a potential suspect since he did not have the opportunity to commit the crime. However, after a few years, it was established via the confession of a serial killer that she was on her way home from work when the killer met her by chance for the second time believing that she was a friend of her brother. This mistaken identity was because she had accidentally met her previously at her brother's home. Therefore, she agreed to have dinner with the killer at a restaurant that had a salad bar. The contents served matched with those of her stomach found during autopsy [58].

Dendrochronology

This field is also called tree ring dating. Dendrochronology is the science that studies dating and annual growth increments of tree rings on woody trees and shrubs [59]. Individual rings contain information about the environment at the time of growth, including the sequence of rings, which can then provide valuable records of conditions at the time. This field was applied to clarify past climates, which can also provide the age and origin of trees. Dendrochronology also has wide applications in forensic timber analysis [60].

Dendrological identification can be conducted following three methods known as visual dendrochronology, chemical dendrochronology, and genetic dendrochronology. While visual dendrochronology involves the study of wood anatomy visually; chemical dendrochronology uses chemical analysis techniques, such as mass spectroscopy, near-infrared spectroscopy, radiocarbon, detector dogs, and stable isotopes; and genetic dendrochronology incorporates DNA barcoding, population genetics, and DNA fingerprinting et al. [61].

Case report

The kidnapping and death of Charles Lindbergh's young son in 1932 were the first modern-era case to use such botanical evidence in court, where the study of dendrochronology played an important role. A wooden ladder was used in entering the second-story nursery to kidnap Lindbergh's son. During investigations, Arthur Koehler, a wood identification expert for the Forest Products Laboratory of the United States Forest Service in Wisconsin, provided evidence against Bruno Richard Hauptman, who was later convicted of the crime. Koehler had an excellent academic record and provided evidence in several cases before the famous Lindbergh trial. During an evaluation of the case, Koehler first analyzed and identified the four tree species used to construct the ladder as yellow pine, ponderosa pine, Douglas fir, and birch by microscopic analysis of wood grain patterns. After that, he analyzed the tool marks left on the wood from the commercial planning mill. He also identified the hand plane used by Hauptman while constructing the ladder. Additionally, Koehler used oblique light in a darkened room to study and analyze the plane patterns left on the wood. He also traced the wood using the mill plain marks on them to a shipment of yellow pine delivered to the National Lumber and Millwork Company in the Bronx, New York. The hand plane marks on the ladder exactly matched those made by a hand plane found in Hauptman's possession. Finally, Koehler linked the annual growth rings and knot patterns on rail 16 of the ladder to a section of wood in Hauptman's attic. He observed that the pattern of knots and growth rings on rail 16 exactly matched an exposed end of the wood in the attic. This finding supports the prosecution's position that a section had been removed to construct the ladder. This case exemplifies the use of dendrochronology in providing critical links to Hauptman's involvement in the Lindbergh kidnapping [4].

Another Important Biological Evidence-Mycology

Mycology is excluded from the Plantae kingdom. However, it is of important biological evidences, as many crimes have been investigated using fungal pieces of evidence. Mycology includes the study of all kinds of fungi, such as molds, mushrooms and yeasts [62]. Forensic mycology is the field of biological science that applies the study, analysis, and identification of fungi obtained from the crime scene to solve legal matters. Forensic mycology can provide various applications. It can provide trace evidence in estimating postmortem intervals, detecting the time of deposition, and finding the cause of death. Applications also involve finding the cause of hallucinations or poisoning, locating buried corpses, detecting biological warfare, and linking a suspect with the crime scene [63]. Few fungi cause disease. But, In contrast, they are also beneficial to their hosts and live on dead and decaying remains [64]. Mostly, fungal palynomorphs are found on stones, bricks, tiles, wooden objects, foodstuffs, leathers, plastics, rubbers, etc. During criminal investigations, the main sources where fungi can be found are soils, sediments, vegetations, plant litter, dead bodies, bloods, and so on. Fungi are dispersed through spores, which are produced either sexually, asexually, or both [65].

Millions of fungal species are present on Earth. Healthy humans are proposed to also have fungal infections, thus, fungi that infect humans are those species tolerant to human body temperature and the body's natural defenses [66]. These species can infect the skin's surface (such as ringworm fungi), some can cause invasive infections, such as candidiasis (thrush), whereas others form more deep-seated infections in the lungs (such as aspergillosis) and other tissues (mycetomas, mycoses) [67]. Alternatively, some species of fungi, like the species of Penicillium, Mucor, Aspergillus, Fusarium, and Geotrichum, which are present on foodstuffs, are proven as useful tools for estimating postmortem intervals [68]. Hence, mycology has now proved to be one of the most important fields of forensic science. However, to date, its potential and application in actual cases have so far been limited [69].

Case report

A young woman was raped and murdered in Dundee. Investigations showed extensive fungal growth

on the exposed parts of her body. These growths were marked in photographs taken at the deposition site. Additionally, the body had been destroyed before a mycologist was consulted. Therefore, taking note of the low temperatures in the vicinity over the past weeks, it was estimated that the body had been there for at least about two weeks. Pollens and fungal spores helped link a suspect to the victim and deposition site. Post Mortem Interval estimate also agreed with the time when the victim and suspect had been caught on a video surveillance camera. The suspect had previous convictions for sexual offenses and was sentenced to life imprisonment for the murder [70].

Conclusions

Forensic botany is a type of prominent and liable tool for crime scene investigations. Botanic evidence can come from contact with suspected crime cases, including death due to suicide, accident, or homicide. Likewise, botanical evidence, such as pollen grains, can be recovered from various sources (victims and offenders), such as on their clothes, in their hair, or even from their respiratory tract, vehicle tires, air filters in cars, and mud. However, the collection and analysis of these botanicals depend upon the skill and knowledge of a forensic expert. The above mentioned cases indicate the importance of botanical evidence in crime scene investigations. Botanical evidence can be analyzed by microscopic, molecular, biological, and morphology identification techniques. Subsequently, the genetic information obtained from this evidence helps predict a possible crime link.

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