Analyzing Botanical Evidence in Crime Scenes: The Role of Forensic Palynology in Investigations

Author 1: Tangasala Tejesh Kumar
M.sc Forensic Science, Chandigarh University, Punjab, India
Mail id: tejesh59@gmail.com
Author 2: Dr. Tina Sharma
Assistant Dean, Department of Academic Affairs, Associate Professor, Forensic Science, Chandigarh University, Punjab, India

Abstract
Forensic palynology is utilized in solving criminal and criminal cases by implementing the knowledge of palynology. By using various analytical techniques such as microscopic analysis, PCR, DNA barcoding, high-throughput sequencing, spectroscopic analysis, soil profile, and so on are being used to provide a link between the suspect, victim, and the crime scene in various manners. This systematic review paper provides a basic awareness regarding Forensic palynology by covering analytical techniques from the basic to the recent advancements along with some case studies that will provide a basic awareness of the concept. This review also highlights the challenges faced by the analysts while analyzing a pollen sample so that the gaps that need to be filled by doing further research can be explored. Researchers, and analysts, who are involved in Forensic botany, Forensic palynology, and General forensic science will find this review's conclusion helpful.

Keywords: Forensic palynology, entomo palynology, pollen identification, challenges in palynology, recent advancements.

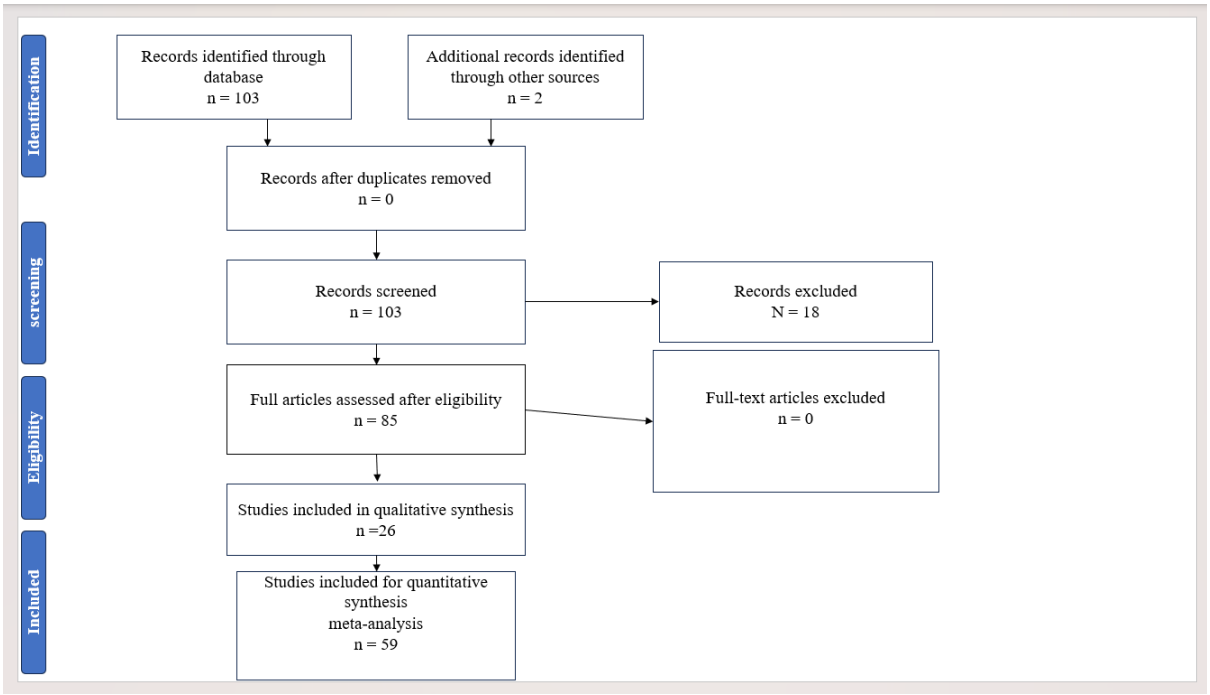
1. Introduction:
Palynology is known for studies related to diverse types of pollen grains, implementation of palynological studies to solve crime scenes and to answer legal questions is known as forensic Palynology. Nowadays the challenge faced by the forensic community is to establish a proper evidentiary value to the pollen grains. As per the studies from the year 1930 to 2018, there were developments in the analysis of pollen grains, but they failed to provide a precise evidentiary value to the pollen grains that are found on crime scenes [1]. During the analysis of pollen grains, the palynological taphonomy provides essential details on microscopic entities, dispersal manner will provide the knowledge regarding specific location and specific time which the pollen may be found, and during the crime scene investigation, a forensic palynologist must know about the production of pollen grains, differentiation according to the taxa, environmental factors and so on to provide an accurate description of the pollen grains that was found in crime scene search[2].

In the field of forensic science palynology plays a vital role but due to a lack of proper scientific knowledge and awareness the science of palynology was being underutilized; the major advantage of pollen grains is they can be transferred between objects from one place to another which is one of the best examples of lord's principle of exchange. Based on the type of pollination method the dispersal amount of pollen grains will vary, for example in wind pollination the dispersal amount was huge, and in 95% of cases these pollen grains are found within a 2-kilometre range. Palynological studies say that the morphological characters of pollen grains will depend on the taxonomical details of a specific plant from which the pollen grain was dispersed. During analysis, the forensic palynologists will analyze the collected pollen samples by using light microscopic methods.[3].In the previous studies, it was noticed that forensic palynology was used to solve many criminal cases[4], [5],[6], [7], [8], [9]. It was interesting to know the implication of palynology on questioned documents. In a study, a paper was dusted using Lillian pollen grains before and after the writing. The results suggested that the pollen grains adhered to the paper more before writing took place were more than the pollen grains found after the writing took place, it was stated that this analysis could be used in the validation of a documented age and the pollen grains can also be collected from the nib of the pen to make a comparative analysis[10]. Although the identification of pollen grains was possible by using microscopic methods, these methods have limitations in that they cannot give accurate information regarding the species level of pollen grains, and the technique is slow in identifying the details. To resolve these issues many robust methods were introduced such as DNA barcoding, PCR, High throughput (HTC)method, Multi parallel sequencing method are being used to get precise and accurate information at the species level, individualization samples, identify the genetic profile from the trace amount of samples, and in also detecting the geolocation of pollen samples[11], [12],[13], [14], [15]. A study was conducted on counterfeit cigarettes, in this case, the cigarettes were counterfeited by using heavy metal which is potentially hazardous. By utilizing the knowledge of forensic palynology, it was found the origin of the tobacco plant was identified based on the pollen grains extracted from the counterfeited cigarettes [16]. Pollen grains of some plants can be strongly adhered to the human skin even after washing hands with standardized methods [17]. The spatial distribution of pollen grains from indoor areas has significance in the field of forensic science, the spatial distribution of pollen grains was studied by placing two types of flower vases in different locations in a single room, in the observations it was found that the spatial distribution of pollen grains were more in undisturbed area rather than disturbed area, based on the results it was concluded that the distribution of pollen grains from indoor flowers can aid in forensic investigators during crime scene reconstruction[18]. A study was conducted on generating pollen prints that belong to various geographical locations of various places by using pelts of different mammals in the L.S.U Museum of Natural Sciences most of the locations that the pollen belongs to are prohibited now so this data can be used in forensic investigations in future. [19]. The purpose and structure of this manuscript are to increase the awareness of forensic palynology, and when it comes to crime, sometimes the perpetrator will try not to leave his clues such as fingerprints, footprints, blood stains, etc. after commissioning of crime, however, the perpetrator will never be able to remove his pollen evidence because the perpetrator doesn’t even have the knowledge that he/she might have brushed against a bush while committing a

crime and got him/herself adhered to pollen grains as it is difficult to be seen. This is the interesting thing where pollen evidence plays a unique role in aiding the investigators to take the lead in crime scene investigations where they are facing complications in identifying and collecting the regular evidence.

2. Methodology

For this review article, we have selected and studied the review and research articles that were released from the year 1986 to 2023 on the concept of forensic palynology and palynology, and for this study, we have selected journals such as Egyptian Journal of Forensic Sciences, Forensic science international, forensic science International: Genetics, etc. We have used search engines like Google Scholar, and PubMed and we have used publishers like Elsevier, Springer, Tayler and Francis, Wiley, etc. For the chart preparations we utilized the data from Scopus and the above flowchart was prepared based on PRISMA guidelines We used MS Excel for preparing the tables and charts, The citation was given in IEE style.



3. Pollen morphology and identification:

To identify the pollen grains, we need to have basic knowledge regarding the morphology of a pollen grain according to its taxa. Apart from the basic parts(Exine, intine, Germ pore, Generative nucleus, Vegetative nucleus, Generative cell), the morphological features include size, shape, walls, etc. In the pollen morphology, the type of aperture was recognized as the basis for identification, there are different types of apertures such as in gymnosperms there will be inaperturate, winged with obscure furrows, in dicotyledons there will be corporate, colpate, corporate and in monocotyledons there will be monopartite, monocolpate. These morphological identifications were made by using microscopic techniques[20]. Different species of pollen that belong to the family of Poaceae can classified by using high-resolution scanning electron microscopy in 2000-12000x and based on the quantitative analysis of surface

ornamentation and texture of different specimens the taxonomy below the family level of each specimen can be identified[21]. The microscopic techniques were also used in examining the tetrads ecto carpus of pollen and utilized in solving sexual assault cases [22],[21],[23]. It was possible to quantify the pollen to determine its viability is possible, in a study the viability of pollen grains was made by using fluorescein (FDA) and propidium iodide (PI) dyes[24]. Studies say that the pollen grains can also be identified by using energy dispersive spectroscopy (EDS) where the chemical and physical properties of pollen along with its adsorbed particulate matter can be identified by maintaining proper electric volts (10kV) and by coating the samples with carbon coating to achieve a reduction of electric charge and conductivity[25]. The chemical composition, morphological identification, and differentiation of pollen grains can be explored based on spatial variation of Fourier transform infrared spectroscopy (FTIR)[26]. According to the studies, the morphological features of pollen grains that belong to different species are studied successfully by using Light and scanning electron microscopy in which some studies give detailed information such as polar diameter, exine thickness, the shape of pollen, equatorial diameter, etc by selecting species such as Duranta erecta L., Datura innoxia mill, Helianthus annus L. and Cyperaceae species,[27], [28], [29].

4. Pollen distribution and dispersal

(a) Factors influencing pollen distribution:

The dispersal of pollen grains can be affected based on criteria such as wind, insects, and animals. The release of pollen grains was considered as the initial stage of wind pollination, wind pollination is the most common and effective type of pollen dispersal in angiosperms, the release of pollen grains from the anther will depend on the conditions such as adhesive theory, distance variation, detachment mechanics that includes aerodynamic forces and mechanical forces, the effects of these methods will be depended on the floral and inflorescence morphological aspects of plant[30], [31], [32]. According to the studies, insect pollination can affect the dispersal of pollen seeds, the dispersal can be influenced by the density of adult trees and the spatial arrangements of suitable sites[33],[34].

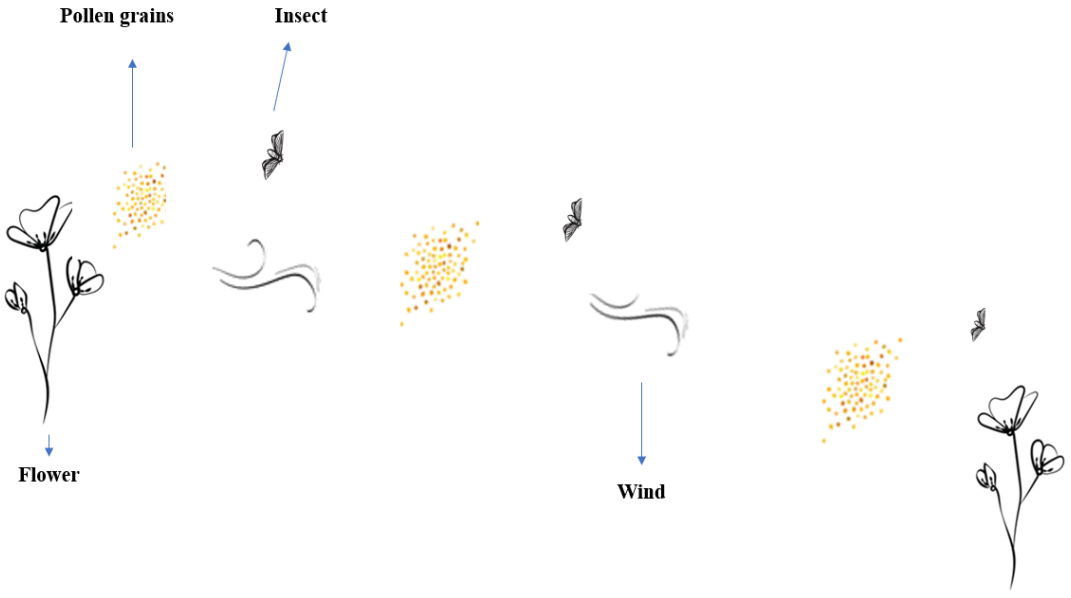


Figure 1: Illustration of anemophily and Entomophily

Table showing different types of pollination:

Classification of pollination	Factor	Pollinator	Type of pollination
Self-pollination	-	-	Autogamy and Geitonogamy
Cross-pollination	Abiotic	Water 	Hydrophily
Cross-pollination	Abiotic	Wind 	Anemophily
Cross-pollination	Biotic	Insects 	Entomophily
Cross-pollination	Biotic	Birds 	Ornithophily

(b) Geographical variation in pollen assemblages

The geographical variation in pollen assemblages can be varied based on the pollinators through which the pollen dispersal will occur. In a study, Macromeria viridiflora was used as a sample. During the analysis by using different bagging treatments, it was found that even though the plant has autogamy features it still has less seed production without pollinators from external sources, and it was found that the geographical variation was dependent on the pressure of pollinators that leads to a change in corolla size[35]. The low visiting of pollen visitors can cause a limitation of pollen and can reduce seed production which results in the geographical variation and distribution of pollen grains, for example, the pollen limitation of Erysimum popovili was due to the lower visiting of beetle fly pollinators [36].

(c) Geospatial analysis techniques for mapping pollen distribution patterns:

The effects of the spatial distribution of potential mates and the change in floral size on seed patterns in pollen species can be studied based on the total stigmatic pollen loads and legitimate pollen loads with variation in floral[37]. Analyzing the previous data helps map the distribution pattern of pollen grains, in a study the existing data to map the distribution patterns of Birch in Switzerland, an Allergan species was used to conclude the mapping and calibration of distribution pattern[38]. The location maps can be generated by using methodologies like grass mapping, tree mapping, weed mapping, and base mapping by which the data on the lands that were occupied by plants by finally combined to achieve a final map that will give detailed information regarding the geographical data to study plant taxa in the UK [39]. Also, in India, various types of pollen were dispersed[40]

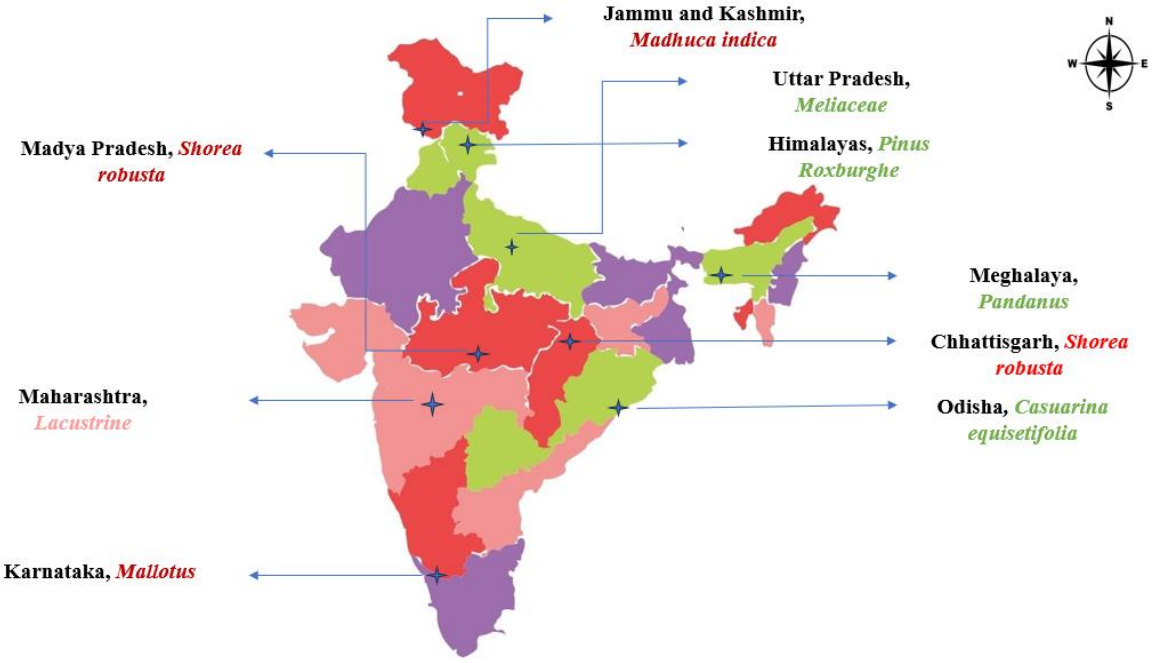


Figure 3: Pollen species found in various states of India.

5. Application of forensic palynology in crime scenes:

Forensic palynology has a wide range of applications in crime scenes, The knowledge of forensic palynology can be utilized to solve various crime scenes.

Table showing a simplified version of case studies:

Case study	Circumstances	Evidence found	Palynological analysis and result	Conclusion	Reference
1	The suspect's motorcycle was stuck in the mud. The suspect claimed that muddy boots from farm work, but forensic palynology linked it to hillside mud. Pollen assemblages from the suspect's boots differed from the workplace, discrediting alibi.	Muddy boot	Matching mud from the suspect's boots to the hill area	Suspect's alibi disproved	[41]
2	The victim was sexually assaulted on a remote beach, suspect was arrested based on the victim's report.	Mud on sneakers	Pollen spores matching beach, dinoflagellates	Suspect linked to assault location	[42]

	Mud on the suspect's sneakers matched with beach dunes pollen spores and dinoflagellates. Evidence linked the suspect directly to the beach location leading to the confession.				
3	The woman was raped by her boyfriend; conflicting alibis were provided. Forensic analysis of the victim's clothes and shoes linked to the victim's described location, not the suspect's claimed location. Strong palynological evidence supported the victim's testimony, leading to the suspect's confession.	Victim's clothes and shoes, and the suspect's shoes	The palynological profile matches the victim's description	The victim's testimony validated	[43], [44]
4	A woman was found murdered, the suspect claimed innocence but lacked an alibi. Fungal growth on the victim's body indicated that the death had occurred at least 2 weeks earlier. Palynological analysis linked the suspect's shoes to pollen from the victim's clothing and the crime scene. The suspect was found guilty of murder and sentenced to life.	Victim's clothes and shoes, and the suspect's shoes	Matching pollen description between suspect's shoes and crime scene	Suspect found guilty of murder.	[45], [46], [47], [48], [49], [50]
5	A woman was found murdered near a wooded park in Central Park. Police found the suspect and when questioned, he denied that he was near the wooded area. The palynological analysis found that the pollen samples from the victim's clothes, the suspect's clothes, and the crime scene were matched, which led to conviction.	Pollen samples from clothing from the victim, suspect, and the crime scene	A pollen match was found between the suspect's clothing. Victim's clothing, and the crime scene.	Suspect linked to assault location	[42]

6	A suspect was arrested on a case of marijuana cultivation. Sniffer dogs traced the route taken by the suspect to where marijuana was growing, but the suspect denied the knowledge of marijuana plants. A pollen match was found in the suspect's soil testing kit and the soil from the marijuana plants	Soil from the suspect's soil testing kit, and pollen from the soil of marijuana plants	Palynological analysis linked suspect to the location of marijuana plants	Palynological analysis proved that the suspect visiting the place of marijuana plants	[41]
7	Two intruders were arrested on charges of burglary and indecent behavior. The intruders denied the incident, however, based on the statement from the victim and her boyfriend, the investigation was run. A pollen sample from an outdoor plant was compared with two intruder's shoes and clothing and found to match as they brushed against the plant while escaping.	Pollen samples from shoes and clothing of intruders and pollen samples from outdoor plant	Palynological analysis linked the intruders to the scene of occurrence.	Palynological analysis proved that the intruders committed the crime.	[6]
8	In a murder case, a search for a female corpse by police led to findings of fungal spores which were mostly found on plants, Glyceria, and Phalaris. The palynological analysis found that the same plant profile was from the suspect's belongings. Based on this palynological evidence the police found two locations visited by the suspect. The body was not found but the suspect confessed that he disposed of the body.	Fungal spores, pollen samples from the suspect's belongings	Palynological analysis traced the locations visited by the suspect by using pollen profiles from his belongings	The palynological analysis led the suspect to the commission of the crime.	[48]
9	In a suspicious hanging case without any signs of suicide, police	Pollen samples from the	The palynological analysis found	The palynological evidence	[42]

	found 5 suspects, but they denied the commission of a crime. During further investigation, a pollen sample was found from the hanging rope, and found that it was from a vegetable farm nearby. Later, the palynological analysis found a match between pollen from the hanging rope and the pollen from the vehicle owned by one of the suspects who uses it for his vegetable farm. This evidence given led to other evidence to solve the case.	hanging rope and the suspect's truck	a match between pollen samples from the hanging rope and the suspect's truck	aided in finding the remaining pieces of evidence to solve the case	

Palynology in decomposition and burial environments:

(a) Understanding the role of pollen in post-mortem interval estimation

When it comes to the investigation of unnatural deaths, the estimation of post-mortem interval (PMI) plays a crucial role in detecting the possible cause of death. According to the studies, botanical evidence like fragments of plants, pollens, and algae can also help estimate the PMI. By using proper sampling techniques, a forensic botanist can analyze the life stage of a plant sample, by detecting the time required for the plant to grow inside the corpse and comparing it with the speed of growth outside or near the corpse also how long the plant is in that stage helps like a biological clock so that a forensic botanist can find the approximate PMI estimation[51], [52]

(b) Analysis of pollen in burial and clandestine graves:

The pollen grains, soil samples, and vegetation analysis can be used to detect clandestine graves, in some crimes, the dead body of the diseased will be shifted from one grave to another grave to avoid detection. In these circumstances, the palynological analysis can be utilized to establish a link between the primary and secondary locations [53], [54].

(c) Taphonomic changes in pollen assemblages over time:

In a study, the taphonomic properties of arctic pollen were studied, and the pollen belonging to the arctic tundra region was analyzed based on changes related to its pollen spectra in its distribution in sub-areal and subaqueous places. It was found that the changes in pollen spectra due to surface water movement and the 0-10% of pollen was ruptured on the sub-areal zone and 20-40% of the pollen from subaqueous zones was ruptured, and the taphonomic factors influenced the changes in the properties of pollen depending on their type of habitat[55], [56]. The pollen distribution and dispersal can also be affected by the wind climate, the places where trees are abundant but still the fallen pollen count was very low, is due to the place being heavily affected by the wind and most of the pollen was removed from the ground so that only a few were able to be found. [57],[58]. The taphonomic knowledge can also be implemented in forensic palynology. Palynological taphonomy can also be defined as all factors that play a role in knowing whether the palynomorph was present at a specific place at a specific time.

The precise prediction of taphonomic variability was achieved it can be used in forensic methods to solve criminal cases[59]. The fossil pollen biotic factors such as human occupation and animal occupation, and the abiotic factors such as volcanic ash can be analyzed by using a taphonomic process. In a study, the reconstruction of vegetation history of the late Holocene of Los Toldos canadon (ravine) from pollen analysis of fossil cave sequence was done. By using the taphonomic analysis it was found that the changes in pollen assemblage are due to the vegetation changes[60]. The regional vegetation changes in animal scats can be explored by using taphonomic analysis, from the inner and outer sections of scats, and it is possible to detect the difference in richness and quality of pollen between the inner and outer regions of the specimen[61].

7. Palynological chronostratigraphic in forensic investigations:

(a) Creation of pollen-based chronological framework in crime scene analysis:

The knowledge of forensic botany has been used in various circumstances to solve crime scenes when it comes to the crime scene of unknown skeletonized or partially skeletonized bodies of the deceased the implementation of forensic botany in aspects such as chronology based on data of pollen analysis, based on plant fragments, and based on the comparative analysis of similarities of plant vegetation, the location of the primary crime scene, the estimation of PMI, and in evolutionary dynamics can be identified so that it can help in solving the case[52]. Most of the studies on pollen analysis were done based on the analysis of outdoor pollen but very few studies explored the indoor species of pollen and its implications in the field of forensic science[62]. The knowledge of chronological analysis of pollen and its implementation can be used in crime scene analysis and reconstruction. In a study it was observed that sediment samples found in footwear need a proper chronological method to differentiate the components of sediment in footwear, the changes in persistence of the pollen on the uppers of two pairs of shoes were observed, and the tapings of pre-marked areas of shoes in chronological order of time interval from 0 to 168 hours was maintained and observed the differences in the pollen persistence percentage on the shoes that were brushed on to the flowering shrubs of Jasminum nudiflorum by using SEM(330x). These findings can be used in forensic science in examining footwear as their finding suggests that the pollen persistence on footwear can be present for a long time and this evidence can be useful in crime investigations[63][64].

(b) Aligning pollen data with historical records:

As mentioned till now, the pollen data has various implications in scientific fields, one of which is in estimating the climatic changes and their impacts on the vegetation. According to the studies, the pollen data plays a crucial role in observing the changes in vegetation in various time intervals along with the geographical scales. As the vegetation responds according to the fluctuation of different climatic conditions, the pollen data such as area coverage, percentage of pollen, taxonomic precision, stratigraphic resolution of individual samples, and so on can be utilized as an appropriate tool that can be used in various analytical techniques to obtain the required information[65][66],[67]. The pollen data can also be used to gather information regarding the quaternary vegetation history, the pollen patterns that are obtained from the pollen data play a precise role in the classification of different pollen from one area to another and changes in the vegetation that occurred due to the past environmental factors and

greenhouse gas emissions[68]. The genetic information of fossils can be utilized in getting continued of genes in plants and it can also be utilized in getting the information regarding past spatial dynamics, by using the amplification method called PCR the cloned sequences of fossil, currently existing pollen species and sequence comparison between them resulted in linking the extant and fossil pollen, according to the studies this type of analysis can be utilized in maintaining the genetic history of pollen species and also utilized in the field of paleoecology[69].

8. Combining the palynology with other forensic techniques:

(a) Integration of palynology with DNA analysis, entomology, and soil science:

The combination of palynological knowledge with other techniques in forensics science will result in broad prospects and advantages in solving criminal cases swiftly. The combination of Palynological knowledge and DNA analysis will give promising results in the identification and individualization of the questioned sample, and this can also be implemented in crime scene investigations [70],[71]. According to the studies DNA sequencing methods such as DNA, and barcoding play an essential role in species-level identification in pollen grains and are implemented in the field of forensic science, in another way DNA sequencing can help in reducing the expertise requirement in identifying the questioned pollen [72]. The combined study of palynology and entomology is known as entomo palynology, this section of palynology helps us gather knowledge regarding the migration patterns, the interrelationship between pollen and insects, visiting time and days of pollinators, protection of plant species from pollinators, etc. This field aids in the extraction of pollen from the insect's mouth and body and helps in knowing the details of pollinators as well as the pollen grains, the dispersal mechanisms of pollen grains can also be obtained by using this type of pollinators. According to the reports, the most useful and economical technique used for this identification is light microscopic techniques[73]. In most of the scenarios the pollen samples will be found on the soil and during the crime scene search these soil samples are being utilized for collecting the samples of pollen grains so that the investigators can link the suspect, and victim to the scene of occurrence by analyzing the pollen samples that are extracted from the soil and by analyzing the other organic and inorganic components of the soil[74],[75]- [76].

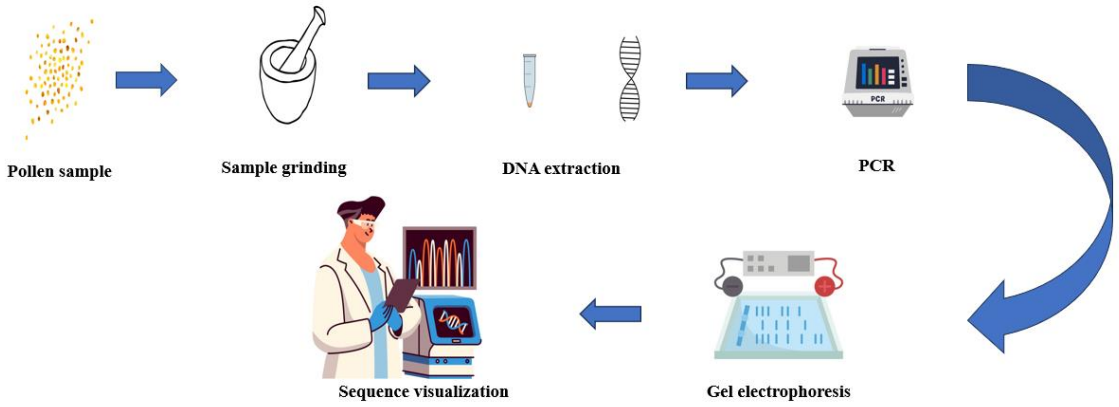


Figure 5: An illustration of the DNA barcoding process for extracting DNA from pollen grains.

9. Challenges and limitations:

The challenges such as lack of pollen calendars in some underdeveloped regions so as a result the workload of the forensic botanist or palynologist will be increased before the investigation and it will consume more amount of time[77]. Pollen contamination because of soil profile and atmosphere is one of the challenges faced by the scientists, the contamination of the pollen samples makes the analysis difficult and leads to accurate results[78],[3]. Properties like pollen dispersal, pollen production, and landscape pollen productivity can affect pollen richness, there is a requirement for high-quality pollen data to sort this problem, but it was difficult to get high-quality data most of the time. The process of observing the taxon richness was very less explored by using quaternary macrofossil assemblages due to the complications that are responsible for various biases, mixed data nature, count-size productivity, dispersions, taxonomic issues, etc, are becoming the challenges for the quaternary microfossil assemblages to measure the taxon richness of pollen[79]. As we know the knowledge of entomo palynology helps in identifying the migration patterns of insects and for this identification we will use the meta-barcoding sequence, there are also some challenges around entomo palynology such as the long-term migration patterns can be affected by the geographical biases in some regions, errors in species assignments due to poor reference databases, complications in species identification due to the factors such as interspecific hybridization, genetic polymorphism, and polyploidy[80]. The pollen dispersion by wind (anemophilous) can also be prone to inaccuracy in the qualitative analysis due to the heavy pollution of particulate matter that is adhered to the pollen samples during the dispersal[81]. In the field of forensic science, the lack of an appropriate number of trained palynologists and not giving proper importance to the pollen samples in the crime scenes are also a big disadvantage in this field more awareness and recruitment of palynologists are needed[82].

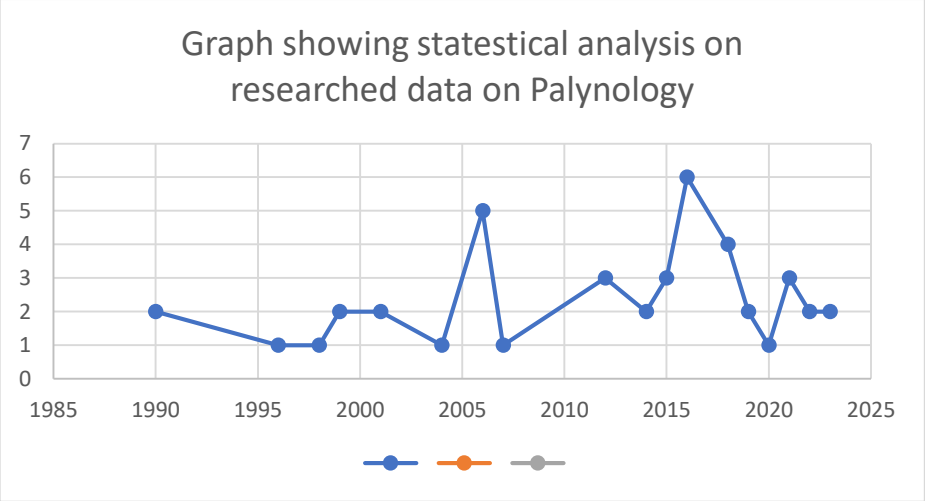
10. Future directions and technological advancements:

Three interesting advancements in palynology have been discussed in this article, in a study a microscopic new method called digital holographic microscopy (DGM) was used to analyze the pollen viability that plays a crucial role in studying dispersal fitness and plant breeding. The working principle of DGM involves the splitting of the laser beam into two parts, one for the sample (the object beam) and the other for the reference. After interacting with the sample, the laser beam will reform according to the morphological characteristics of the sample and then finally provide a 3d hologram image by combining it with the reference beam, this result was further recorded by using a charged coupled device camera and processed by computer algorithms[83]. Analyses of quaternary pollen samples are mostly carried out by using acidic treatment but while analyzing the fossil samples these acidic sampling methods were not recommended by the scientists because of some hazardous reasons, studying the pollen samples that are present in clay became a challenging task for the scientists because these clay particles will be adhered to the samples and leads to inaccurate observational results and acidic methods was used to remove these clay particles, in a study, the morphological characters of pollen grains that belong to 3 different areas (Lake, Peat, Swamp) of Brazil was analyzed by using an acid-free treatment.

In the study, chemicals, potassium hydroxide as humic acid remover, sodium pyrophosphate, and sodium metaphosphate as a clay remover, zinc chloride as a precursor for floatation of pollen grains. During the analysis, three hundred pollen samples were analyzed and found that it was giving effective results when compared with acidic methods[84]. Automated pollen classification is a recent advancement that was made by combining artificial intelligence (AI) and palynology, A study was conducted on this concept and utilized this concept in giving information regarding the climatic changes and pollen forecasting models, in the study 53 plant species belonging to the region of European and Northern American angiosperms and gymnosperms was analyzed, in this process the combination of image flow cytometry and guided deep learning to give accurate taxonomic information by analyzing pollen from environmental samples. It was reported that this method could offer details regarding more revolutionary aspects of palynology[85].

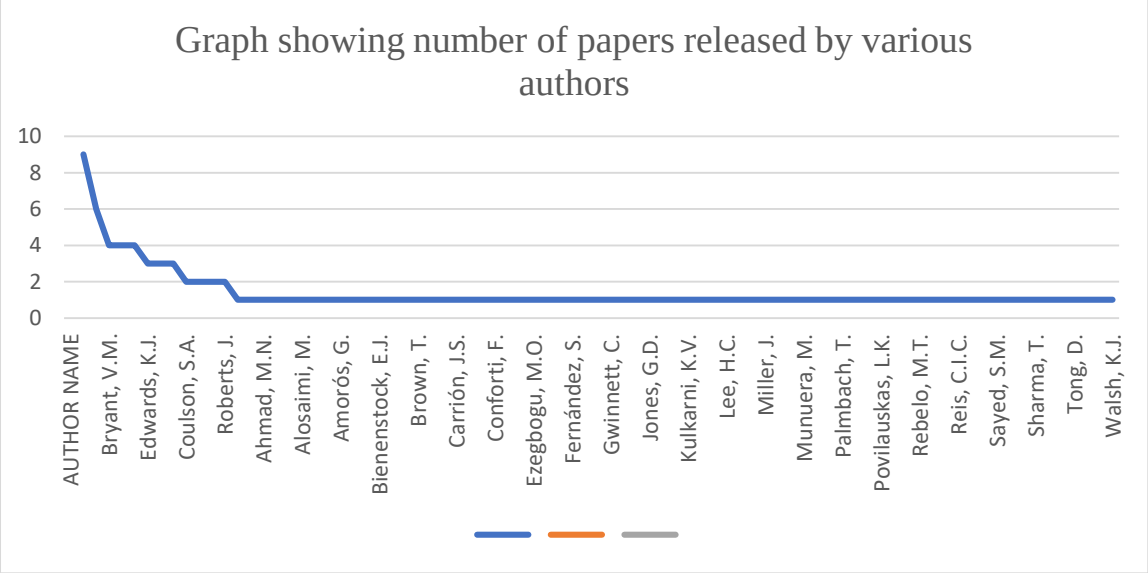
10. Statistical reports and pollen extraction table:

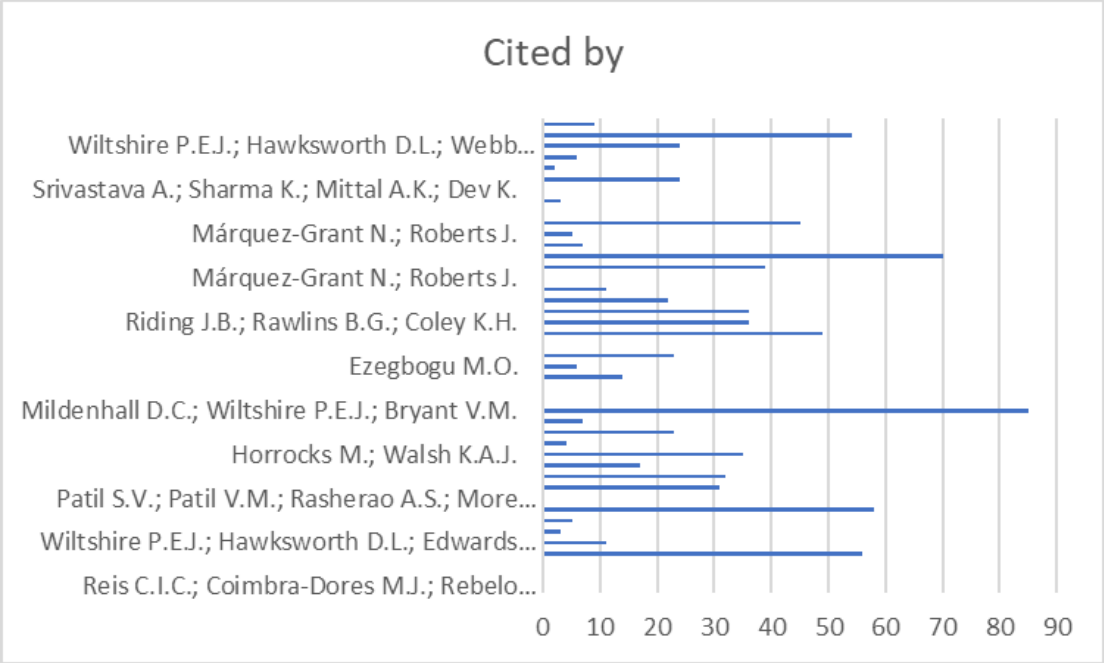
(a) Statistical analysis of researched data on palynology:



In the above graph, we have mentioned the statistical analysis of researched data on palynology, in this graph, some data describes about number of articles that were published on the concept of palynology between the year 1985 to the year 2025.

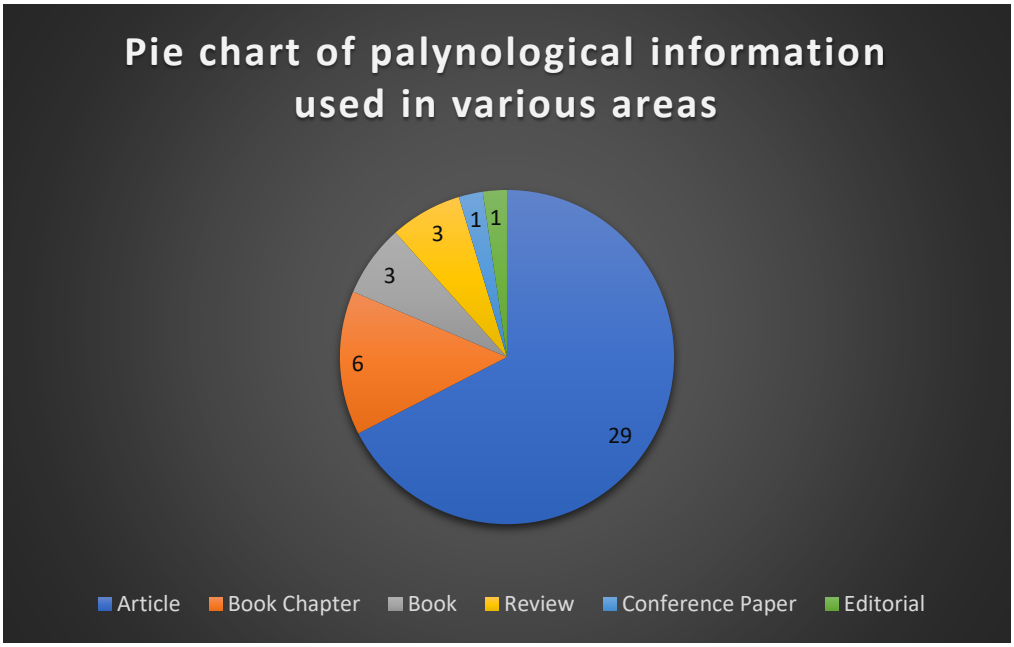
(b) Number of papers released by various authors on the concept of palynology:





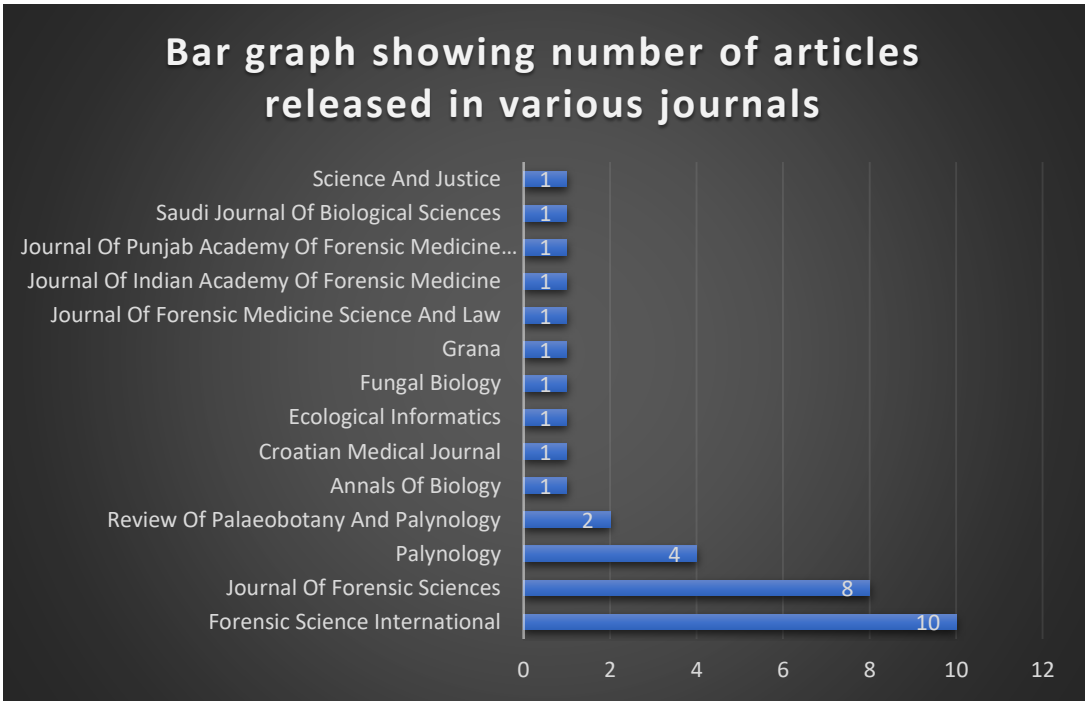
In the above-mentioned line graphs, we have mentioned about number of articles released by various authors on the concept of palynology, according to the graph it was mentioned in a way starting from the highest number of articles to the lowest number of articles that were released by various authors. And in the second graph, we have randomly given the same details.

(c) Pie chart representing palynological data implications:



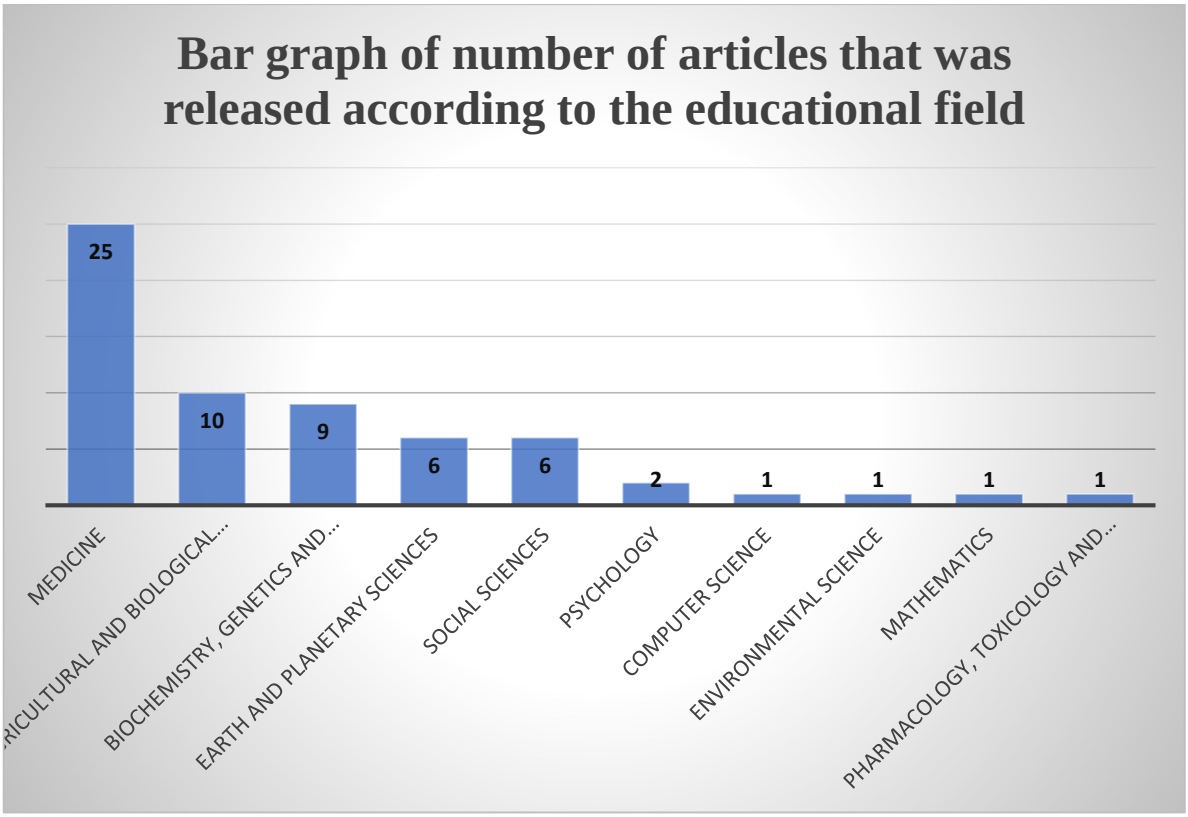
In the above pie chart, we have mentioned various areas like books, articles, conferences, etc., where the information on palynology was used, based on the above pie chart clearly shows that, mostly in articles this concept was discussed and less likely in the areas of editorials and conferences.

(d) Bar graph showing the number of articles released in various journals:



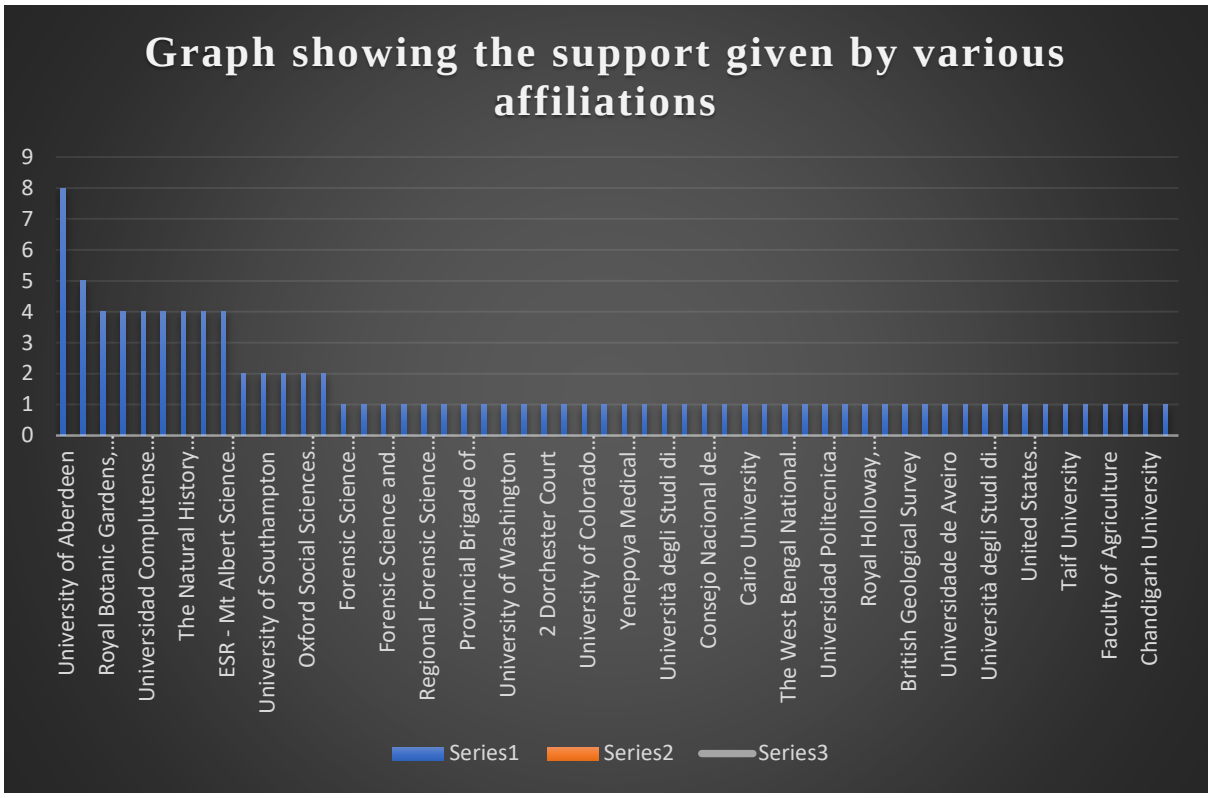
In the above bar graph, we have mentioned the number of articles on palynology, that were released in different types of journals. According to the bar graph, most of the articles were released by “Forensic Science International” journal and the second highest was “The Journal Of Forensic Sciences”.

(e) Bar graph representing the usage of palynology in various educational fields:



In the above graph, we have mentioned the number of articles on palynology, that were released by various educational fields. Based on the above graphical representation it was clear that the fields of medicine, agriculture, and biology have given much importance to the concept of palynology.

(f) Graph showing various affiliations that supported the concept of palynology:



In the above graph, we have mentioned various articles on the palynology concept that were supported by several affiliations. Based on the above graph it was clear that most of the articles were affiliated with the University of Aberdeen.

(g) Table showing methods used by various studies to extract pollen from different samples:

S/no	Sample	Extraction method	Pollen species	Results	References
1	Clothing	Centrifugation and acetolysis	Quercus, Poaceae, Pinus	Geolocation Was identified based on pollen analysis	[5]
2	Stomach contents	Acetolysis	Brassica	Linked the deceased with evidence from the suspect's location	[8]
3	Counterfeit cigarettes	Extraction solution	Ambrosia, Poaceae	Identified the counterfeit	[16]

		and Centrifugation		cigarette from genuine one	
4	Hand wash water sample	Micromesh technique	Tulipa gesneriads Amelanchier alnifolia	Adherence of pollen grains on skin even after washing	[17]
5	Mixed pollen samples	Next generation sequencing	Mixed pollen sample	Identified the taxonomic depth in mixed pollen species	[13]
6	Cotton swatch	Next generation sequencing	Pinus echinata	A DNA profile was generated	[14]
7	Mammal pelts	Vacuuming, centrifugation, and acetolysis	Quercus, Dodonnaea viscosa, ceanothus	Pollen prints were generated	[19]
8	Anthers	Acid treatment and crushing	Cenchrus biflorus, Datura innoxia. Cestrum nocturnum	Individual pollen morphology was studied	[27]
9	Curtain(fabric)	Detergent washing	Cluding justicia, Olea chrysophylla	The authenticity of the fiber was confirmed	[42]
10	Clothing, penile, and vaginal swabs	Centrifugation, Surfactant solution, acetolysis	Betula, Quercus, Sambucus nigra	Linked the suspect and victim to the actual scene of occurrence	[43]
11	Clothing, footwear, soil, and leaf litter	Acid treatment, safranin staining	Clematis, Ligustrum, Greselinia	The pollen profile was matched with the victim's clothing and the suspect's footwear	[45]
12	Soil, Clothing	Washings, Filtration, centrifugation	Quercus, Betula	The pollen profile was matched from	[47]

				the victim and suspect	
13	Soil, footwear, fabric	Chemical treatment with lycopodium tablets	Chenopodiaceae, Pinus, Quercus	Palynological identifications were made	[49]
14	Footwear	Heavy liquid separation, acetolysis	Morus nigra, Platanus, Cupressaceae	Pollen identifications were made based on a comparison of assemblages	[50]
15	Soil, clothing	Acid treatment, acetylation	Pinus, Quercus, Picea Fagus, Carpinus	Pollen profiles provided the link between primary and secondary graves	[53]
16	Wedge ice, current soil, frost mounds	Acetolysis	Pinus, Cyperaceae, Poaceae, Alnus, Betula etc	Regional and local taphonomic changes were explored based on pollen content difference	[55]
17	Peat	Acetolysis	Xanthomyrtus, Dacrydium, Syzygium	Pollen analysis revealed the spatial distribution of vegetation	[56]
18	Sphagnum pollsters	Acetolysis, safranin staining	Pinus, Alnus,	Pollen percentage analysis explored the effect of wind on pollination.	[57]
19	Coprolites, scats	acetolysis	Mimosoideae, Poaceae, capparaceae, Asteraceae	The richness of pollen preservation was found to be prominent in	[61]

				both fossilized and fresh animal scats.	

In the above table, we have mentioned the methods that were mentioned in various studies to extract pollen from different samples, based on the table as mentioned earlier we have noticed that most of the studies have used acetolysis to extract pollen from various samples such as clothing, stomach contents, mammal pelts, footwear, current soil, etc. It is common knowledge that the extraction methods were used to filter, separate, and identify the pollen from foreign materials.

12. Conclusion:

Forensic palynology assists in criminal investigation by providing a link between the suspect, and victim, to the crime scene. It helps detect the primary and secondary crime scenes, helps detect the clandestine graves, and so on. This field was getting underutilized by forensic investigators due to a lack of expertise. This review article will provide a basic awareness regarding the concept of palynology and how it will be implicated in the field of forensic science in solving criminal cases. Now we have entered the era of Artificial intelligence, with the help of AI and modernization techniques in the coming time we can increase the speed and accuracy of palynological results so that cases can be solved way faster than in earlier times. There is still a need for in-depth research in this field to give more precise techniques that will provide a piece of accurate information in taxonomical details from pollen samples which will also aid in increasing the evidentiary value of pollen evidence in the legal systems.

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