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ADVANCEMENTS IN FORENSIC FINGERPRINT DEVELOPMENT: NANOTECHNOLOGY-DRIVEN APPROACHES - A CRITICAL REVIEW OF ORGANIC, INORGANIC, AND HYBRID COMPOSITION POWDER COMPOSITIONS FOR LATENT FINGERPRINT VISUALIZATION

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ABSTRACT

Latent fingerprints (LFPs) are an essential biometric evidence source for forensic fingerprint analysis, which is a fundamental component of criminal investigations. Despite their effectiveness, traditional techniques like powder dusting pose health and environmental risks since they contain harmful substances like carbon black and lead. LFP visualization has been revolutionized by recent advancements in nanotechnology, which have provided enhanced sensitivity, contrast, and resolution. In addition to improving fingerprint detection, gold, silver, zinc oxide, and carbon-based nanoparticles, as well as organic, inorganic, and hybrid powders, solve sustainability and safety issues. This paper examines how fingerprint development methods have changed over time, contrasting traditional methods with cutting-edge nanomaterial-based solutions. It talks about the chemical makeup of fingerprint remains, which is impacted by variables including age, food, and surface pollutants, and emphasizes the function of Automated Fingerprint Identification Systems (AFIS) in digital analysis. While fluorescent polymer-based materials and rare-earth-doped nanoparticles enhance detection under UV light, new organic and biodegradable powders, such as herbal and dextran-based formulations, offer environmentally benign substitutes. Because of their capacity to cross biological barriers, nanoparticles present possible health and environmental hazards despite their benefits, calling for thorough safety evaluations. Future directions for forensic fingerprint research are discussed in conclusion, with a focus on the necessity of high-performing, non-toxic solutions that strike a compromise between effectiveness and occupational and environmental safety.

Keywords: Fingerprinting, Organic powders, Inorganic powders, Nanotechnology, Fingerprint development

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INTRODUCTION

A fundamental component of criminal investigations, forensic fingerprint analysis offers a distinct and reliable way to identify people. Important biometric information is contained in latent fingerprints (LFPs), but specific methods are needed to visualize and improve them [**1**]. Although conventional techniques, including powder dusting, have been in use for many years, worries about the effects on the environment and human health have prompted the creation of cleaner and more efficient substitutes [**2**]. By providing high-resolution imagery, better contrast, and increased sensitivity, nanotechnology has completely changed forensic fingerprinting. Gold, silver, zinc oxide, and carbon-based nanoparticles have all shown impressive results in fingerprint visualization on a variety of surfaces. Furthermore, forensic capabilities have been further enhanced by the creation of organic, inorganic, and hybrid fingerprint powders, which address safety and environmental problems. This article explores the progress of fingerprint development processes, contrasting traditional methods with contemporary efforts driven by nanotechnology [**3**]. In addition to addressing

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advancements, difficulties, and the direction of fingerprint research in forensic science, it also examines the function of Automated Fingerprint Identification Systems (AFIS) in digital analysis. In forensic science, FPs have been used to identify a person by their physical signs. Nowadays, the role of nanoscience and nanotechnology has become an essential boosting agent among many LFP enhancement strategies, which rely on the increased surface area of deposition and fluorescence abilities. Secretions from the eccrine (sweat), sebaceous, and apocrine glands on the hand, head, and nose make up latent fingerprint residues. Water (>98%), minerals (0.5%), and chemical substances (0.5%) are all present in sweat. Sebaceous sweat contains glycerides, fatty acids, wax esters, squalene, and sterol esters, whereas eccrine sweat contains proteins, urea, amino acids, uric acid, lactic acid, sugars, creatinine, and choline. The chemical makeup of latent finger impressions is influenced by a variety of donor-related characteristics, including sex, age, food, medication, disease type, and the presence of pollutants on the fingertips' surface [**4**].

The deposited FPs at the crime scene are categorized into three parts:

1. Patent (positive/negative)
2. Plastic (molded/plastic)
3. Latent (invisible prints) [**5**]

There are five types of fingerprints: whorl, left loop, right loop, tented arch, and arch. A fingerprint image's singular points (cores and deltas) are extracted by the algorithm, which then classifies the image according to the quantity and positions of the unique points found [**6**].

Fingerprint identification is based on two basic premises:

1. Persistence
2. Individuality [**7**]

TRADITIONAL V/S MODERN TECHNIQUES

Although several developments have occurred in the detection of invisible fingerprints, the most conventional technique remains the powder dusting approach, which was first described in 1891. The necessity for alternative fingerprint powders primarily stems from the various health risks associated with traditional fingerprint powders when used in the workplace. Forensic and law enforcement professionals who handle inorganic fingerprint powders, for instance, are at serious risk of heavy metal toxicity. Consequently, powder formulations based on lead and mercury are no longer relevant. Numerous studies on the health risks associated with fingerprint powder exposure at work have been published. Common fingerprint powders like carbon black powder and cyanoacrylate fumes have also been connected to health hazards [**8**] .

The word "dwarf," which implies small or one billionth of a meter, or 10–9, which is approximately equal to one nanometer (nm), is the source of the name "Nano." In other words, this scale is about 3–5 atoms wide, or 40,000 times thinner than the width of a virus or human hair (100 nm). The development of materials with a size between 1 and 100 nm is the primary goal of nanotechnology [**9**]. Nano-forensics, a subfield of forensic science, has embraced it because of its many uses. Nano-forensics is a rapidly emerging field of innovation that makes use of nano-based technology [**10**].

Latent fingerprints have been developed using nanotechnology. Nanoparticles of gold, silver, zinc oxide, silicon oxide, aluminum oxide, carbon, quantum dots, and rare earth metals have all been shown to be highly effective at creating latent fingerprints from a variety of surfaces. For improved outcomes, these nanoparticles have also undergone a number of changes. The chapter has covered the uses of these nanoparticles in fingerprint development, different variations, and their advantages and disadvantages. The chapter's conclusion includes a discussion of the potential applications of nanotechnology in fingerprint development [**11**].

METHODOLOGY

Using various keywords, the first search for pertinent research publications was carried out on Google Scholar. To guarantee access to thorough and excellent research publications, various search strategies were used by adjusting keywords and search filters. Finding papers that provided a range of viewpoints and the most recent information on latent fingerprint powder development was the goal. To guarantee access to peer-reviewed research and trustworthy information, data were gathered from forensic science journals that are well-regarded, in addition to Google Scholar. A thorough screening process was used to find research publications that provide comprehensive details on both organic and inorganic powders [**12**].

Inclusion and Exclusion Criteria

Studies were included if they offered thorough details on the overview of the review, with an emphasis on the composition of the powder, its physical and chemical characteristics, and its effects on the environment. To preserve the caliber and coherence of the information, articles that lacked clarity, relevance, or solid facts were eliminated from the evaluation. The results from the chosen research were assessed using both qualitative and quantitative methods. The research was divided into three main categories to create a comparative framework. We studied and examined research on the chemical makeup and interactions of powders. Additionally, studies addressing the powders' safety, environmental problems, and biodegradability were analyzed, as well as studies concentrating on their physical characteristics, sensitivity, and surface effectiveness. In order to derive significant implications for their perspective, pertinent facts from each category were chosen and combined [**8**].

Health and Environmental Concerns

In addition to posing a risk to the user's health, fingerprint powders employed in the powder approach have the potential to contaminate the environment. Certain carcinogen-containing powders, like those based on lead or mercury, have been phased out of use. 5, 6 Furthermore, carbon black in black powder and metal components in modern magnetic powders may induce respiratory illnesses like pneumoconiosis. That is to say, the majority of fingerprint development powders contain chemicals that are harmful to long-term health. Additionally, the powder's particle size ranges from 1 to 10 μm, which is similar to the size of normal fine dust (≤ 10 μm). While dust particles ≤2.5 μm could create major health issues when they enter the body through the respiratory tract and bloodstream, fine dust particles ≤10 μm could enter through the respiratory system and build up in the lungs. Therefore, it is advised to wear safety gear, such as masks and goggles, to prevent powder inhalation, and the significance of adequate ventilation is underlined [**13**]. Nevertheless, depending on the circumstances and settings under which they operate, it is difficult to guarantee the safety of forensic investigators. Additionally, it's unknown how well the mask and goggles stop fine powder inhalation, which is often advised for gathering evidence. While studies outside of Korea have found that occupational exposure to fingerprint powder is linked to higher-than-expected incidences of skin and visual impairment, it may be challenging to generalize powder as the direct cause of the diseases. A questionnaire survey of forensic investigators in Korea revealed that respiratory, eye, and skin diseases were the most common diseases among forensic investigators. Additionally, powder pollutes indoor air and the environment, necessitating laborious cleaning and washing following the inquiry. Additionally, it can reduce the effectiveness of the forensic investigator‘s job [**14**, **15**].

Time Period	Advancement
1000 BC	Fingerprint Signatures
1686	Fingerprint Analysis
1823	Pattern Documentation
1858	Contract Identification
1880	Forensic Potential
1891	Latent Development
1894	Fingerprint Adoption
1897	Classification System
1920s-1930s	Forensic Labs
1950	Tape Lift Method
1960s	Automated Recognition
1976	Superglue Fuming
1984	Automated System
1990s	System Adoption
2000s	Nanoparticle Powders
2010s-2020s	Eco-Friendly Powders
2020s	Safer Nanoparticles

Figure 1: Chronological timeline data: Major milestones in fingerprint powder development and fingerprinting technology.

IMPORTANCE OF POWDER COMPOSITION

The following are some crucial requirements that a good fingerprint powder formulation must meet, in addition to toxicological concerns. The powder should have tiny, fine particles. If not, it can make it impossible to examine significant ridge pattern elements, especially the third-level details. The surface under examination shouldn't be physically or chemically drawn to the fingerprint powder's ingredients. This may have anything to do with the powder's sensitivity. Aluminum powder is less sensitive than aluminum flakes, for instance. Sensitivity isn't always a requirement, though. It is difficult to meet this requirement since the fingerprint powder and the surface may be the same color. However, the fingerprint powder should provide a good color contrast on all surfaces. It should be possible for the powder to flow reasonably and not cause caking, which would make it unusable. The powder should have a long shelf life and be stable. There shouldn't be any harmful elements in the powder formulation. The cost of the powder shouldn't be prohibitive. It is better if the powder is made using easily accessible, everyday substances. The practical applications of complex substances may be limited due to their difficulty in obtaining. Graphite powder is an example of a clumsy powder composition [**16**]. Formulating a universal fingerprint powder that satisfies all of the aforementioned requirements is quite challenging. As a result, numerous researchers have developed thousands of powders over time. No single powder is suitable for every situation involving various surfaces, situations, and the type of fingerprint being examined, according to fingerprint specialists. As a result, every fingerprint needs to be handled differently. Thus, choosing the right fingerprint powder for a given fingerprint is important and depends on a number of parameters [**14**].

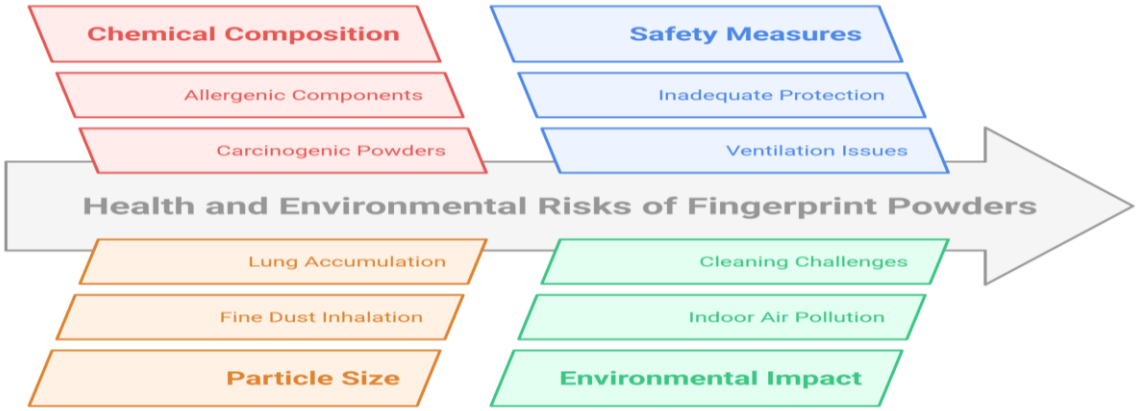


Figure 2: Health and environmental concerns of using fingerprint powders.

METHODOLOGY OF FINGERPRINTS DEVELOPMENT

Using a glass-fiber or camel-hair brush, a finely split formulation is applied to the fingerprint imprint in the powder technique for latent fingerprint detection. The ridge pattern is defined by the powder's mechanical adhesion to the perspiration residue. The powder does not stick to the furrows where there is no fingerprint residue. As a result, the powder formulation is readily blown off the furrows but adheres to the ridges. The latent print is said to have evolved when the ridge pattern is evident due to the powder's typical coloring [**17**].

CLASSIFICATION OF POWDER TYPES FOR LATENT FINGERPRINTS DEVELOPMENT

According to Locard's Principle, one cannot behave with the ferocity of a criminal act without leaving numerous traces. Fingerprints can be of several types. Few of them are visible to the unaided eye. Most of these are so-called latent finger markings, which must develop before they can be observed, documented, and utilized during an inquiry [**18**, **19**].

ORGANIC POWDERS, DERIVED FROM NATURAL SOURCES

FOOD MATERIALS AND FOOD ADDITIVES

Historically, commonly available food materials and additives have the potential for developing latent fingerprints due to their accessibility, low cost, and non-toxic nature. Turmeric powder is one of the most effective agents, largely because of its main active compound, curcumin, which interacts with fatty acids and glycerides in fingerprint residues through hydrogen bonding, resulting in good adherence and clear visualization on various surfaces. It generally performs well on both porous and non-porous surfaces, although it shows poor contrast on skin. Other food powders such as cocoa powder, corn flour, custard powder, baking soda, baking powder, black salt, and edible food colorants also have potential, with cocoa powder—rich in compounds like caffeine and polyphenols—performing notably well alongside turmeric. On surfaces like pharma-col, clear polythene, and white ceramic tiles, powders like custard, corn flour, and baking soda often don't create a strong contrast. Despite having ascorbic acid and capsaicin, red chili powder is typically useless because it adheres poorly to fingerprint residues on non-porous surfaces. Numerous spices have also been taken into consideration, such as cumin, coriander, cinnamon, and pepper powders, as well as garam masala, which is a mixture of cumin, coriander, black pepper, cardamom, and cinnamon. Gram flour, which comprises amylase and starch, exhibits promise because of its ability to interact with the lipid components of fingerprints, creating recognizable ridge patterns and good contrast. While some spices, like red chili and cumin, give partial ridge features, other spices, including coriander powder, kitchen king masala, and garam masala, tend to create less noticeable patterns. Latent prints can be successfully developed on a variety of surfaces, including glass, metal, wood, plastic, tile, and steel, using natural powders like charcoal, betel leaf, and neem powder, which are safe and environmentally friendly substitutes for traditional fingerprint powders. Because it lacks the resinous composition required for adherence to the oily and moisture components of fingerprints, paprika, which gets its striking red color from capsanthin and capsorubin, is typically inefficient for fingerprint creation. Particularly on non-porous surfaces, cinnamon powder produces distinct and intricate sebaceous fingerprint patterns. Latent fingerprints can also be visualized with common food colorants like orange-red, lemon yellow, and brilliant green dyes; findings are especially visible on surfaces like aluminum.

In comparison to traditional fingerprint powders, this move toward natural alternatives seeks to offer more accessible, safe, and reasonably priced options [**14**]. Following these ground-breaking studies, other research teams have carefully investigated the potential of different common household and natural powders for forensic fingerprint detection. This area

includes research on natural powders derived from medicinal herbs such as Euphorbia tirucalli, Rhinacanthus nasutus, Zingiber montanum, and Solanum Indicum L. These powders may have fluorescent properties for better detection and have fewer adverse effects. Two more intriguing natural materials that have been studied are betel leaf powder and charcoal powder, both of which have shown effectiveness on non-porous surfaces [**20, 21**].

Plant Materials

Due to their inherent qualities, a variety of powders made from plants have been used for latent fingerprint detection. Spores of Lycopodium are still a traditional plant material that can be utilized either by itself or in conjunction with other materials. The powder of Spirulina platensis is distinguished by its intense near-infrared (NIR) fluorescence, which is ascribed to pigments known as phycocyanins that absorb orange-red light and release fluorescence into the NIR spectrum. This NIR fluorescence reduces background interference on substrates that fluoresce under UV light, like paper and polymers, giving it an edge over traditional UV luminous powders. Because of its green hue, spirulina powder also contrasts well with a variety of backdrops and works well on sebaceous fingerprints. Research has also been done on other powdered marine plants, such as wheatgrass, spinach, kale, lime, Chlorella, broccoli, and moringa. It has been found that at 850 nm, the luminescence of these plants decreases significantly.

Carbon Powder

Using a glass-fiber or camel-hair brush, a finely divided formulation is applied to the fingermark impression in the carbon powder method for latent fingerprint detection. The ridge pattern is defined by the powder's mechanical adhesion to the perspiration residue. The powder does not stick to the furrows where there is no fingerprint residue. As a result, the powder formulation is readily blown off the furrows but adheres to the ridges. The latent print is said to have evolved when the ridge pattern is evident due to the powder's typical coloring. The powder that provides the finest color contrast with the surface being dusted should be chosen. As a result, fingerprint powders come in a range of colors and compositions for commercial use. On dark surfaces, the grey powder, which is made of aluminum dust, is applied. Because they will photograph black, it is also used on mirrors and metallic objects that have been polished to a mirror-like sheen. The charcoal-based black powder is applied to surfaces that are white or light in hue **[22].**

SYNTHETIC ORGANIC POWDERS

Ninhydrin

Siegfried Ruhemann accidentally made ninhydrin in 1910, which led to its initial description [**23**]. Ruhemann published several papers describing this and other reactions after seeing that the new substance produced a purple result when it reacted with skin and amino acids. He suggested a structure for the intensely colored substance, now referred to as Ruhemann's purple, and offered insights on how the reaction may be used to find traces of protein products and amino acids in biological materials. Since this first report, ninhydrin has quickly established itself as a vital technique for detecting latent fingerprints; as early as 1959, its extensive use across jurisdictions was noted. Nowadays, it's one of the most widely used techniques for detecting fingerprints on paper and other porous materials. The reddish-orange pigment lawsone, which is found in henna powder made from Lawsonia inermis, reacts with the fatty and amino acids in perspiration to produce fingerprint patterns. Naturally occurring henna can absorb moisture from the air and darken over time, improving the visibility of fingerprints. The pigment is usually released in acidic environments. In contrast to prints on porous or textured surfaces like granite, leather, paper, cardboard, and wood, henna-developed prints are typically easier to spot on non-porous substrates like foil paper and plastic. Certain formulas' lack of acid may restrict lactic acid release and, thus, the clarity of the produced prints.

Durian seed powder, which is mostly made of starch, sticks to fingerprint remnants by forming hydrogen bonds with the carboxyl and hydroxyl groups of the powder and the sebum components. Its white hue makes it less effective against light-colored backdrops, yet it clearly shows fingerprints on many surfaces. On a variety of non-porous surfaces, Gambir powder, which comes in yellow to brown hues, has been utilized as a green fingerprint developer to create distinct prints with distinct ridge characteristics. Gambir powder's adhesion is influenced by its particle size; coarser particles work better on some surfaces while finer particles work better on others [**24**].

5-METHYLTHIOINHYDRIN (5-MTN)

As part of a project for the U.S. Secret Service, 5-Methylthioninhydrin (5-MTN) was first made and used as a fingerprint reagent in 1990. This homologue has the same reaction with amino acids as ninhydrin. Consequently, 5-MTN-developed fingerprints resemble ninhydrin-developed fingerprints in terms of color. Similar to ninhydrin development, 5-MTN-treated fingerprints require heat and humidity to develop. The 5-MTN-developed fingerprint turns pink after being treated with a zinc salt [**25**].

INORGANIC POWDERS

Metal-Based Powders

Most metal-based fingerprint powders are composed of fine metal particles that adhere to latent fingerprints and enhance their visibility on various surfaces. Because of its great sensitivity, ease of usage, and ability to produce fine continuous ridge detail, aluminum is the metal most frequently used in these powders. Other often used metals include

bronze, gold, copper, iron, and zinc; each has unique properties that make it suitable for a range of forensic uses [**26**]. Since these powders are composed of flat, smooth metallic flakes that provide developed fingerprints with a high degree of clarity and reflection, they are typically categorized as flake powders. In countries like the UK, aluminum powder is particularly popular since it works well on a variety of surfaces, such as glass, metal, and varnished wood [**27**]. Because they include minute iron particles, a particular kind of metal-based powder called magnetic powders is applied using a magnetic applicator rather than a brush. This method reduces the chance of damaging delicate fingerprint ridges while enhancing detail development. Magnetic powders come in two varieties: single-component, where the magnetic particles themselves produce the print, and two-component, where the magnetic particles carry non-magnetic powders. These powders come in a variety of hues, including fluorescent, silver, and black, to produce contrast on a range of backgrounds. Fluorescent metal-based powders contain dyes that fluoresce when exposed to ultraviolet or other light sources, which is useful in instances where standard powders would not be able to display fingerprints on unclean or multicolored surfaces. Similarly, nano powders comprised of extremely thin particles offer improved ridge definition on both new and old prints due to their small particle size [**28**].

Despite the great effectiveness of metal-based powders, some previous formulations contained dangerous ingredients like lead or mercury, which have since been removed because of health concerns. These substances are eschewed in favor of safer metal oxides and carbon-based components in modern formulations. Because of their adaptability, sensitivity, and capacity to create distinct, detailed fingerprints on a variety of smooth, non-porous surfaces, metal-based powders such as magnetic silver powder and aluminum powder are frequently employed in forensic practice. To preserve the integrity of the evidence and prevent contamination, the powders

are frequently administered carefully and packaged in tamper-evident packaging [**29**].

SILVER NITRATE REAGENTS

Silver nitrate, or AgNO3, in an aqueous solution ranging from 1 to 3%, was one of the first chemicals used to create latent prints on porous surfaces. As early as 1891, it served this function. Alcohol is now a common ingredient in most formulas to speed drying and increase wetness (lower surface tension). An ethanol-based 3% (w/v) silver nitrate solution (90 percent ethanol and 10 percent water) creates prints on water-repellent materials like Styrofoam, waxed paper, and cardboard. The elemental silver formed is not silver in color; rather, it is dark brown to black. This is because the silver deposits as a collection of small silver particles, called colloidal, creating a very porous surface that absorbs a lot of light. The rapid reduction of the silver ions results in the creation of dark, light-trapping silver [**30**].

METAL SALTS AND NINHYDRIN

In a biological setting, Ruhemann's purple and metal salts, like copper, zinc, cadmium, and cobalt, reacted to maintain ninhydrin spots on chromatograms. Depending on the salt employed, the formation of a metal-salt complex changes Ruhemann's purple from a deep violet to either red or orange. When viewed at 490–510 nm, where the metal–Ruhemann's purple complex has an absorption maximum, the lighter color may offer a stronger contrast against a dark background [**31**].

ZINC OXIDE

To identify latent fingerprints, semi-spherical zinc oxide nanoparticles with a diameter of 10 nm to 30 nm have been created, with encouraging outcomes. To improve the visibility of latent fingerprints, zinc oxide has been deposited on polyethylene terephthalate surfaces using thermal evaporation procedures with molybdenum boats. Zinc oxide deposited on a tiny coating of gold seed was shown to be more successful than deposition without the seed layer, resulting in typical fingerprint growth. This discovery validates that zinc oxide can be deposited in the spaces between fingerprint ridges without the need for conventional techniques like cyanoacrylate fuming or gold thin films. This is explained by the electrostatic interaction between the organic molecules found in sweat remnants and zinc-oxygen bonds. Additionally, the data show that distinct fingerprint patterns, including first-, second, and third-level ridge features, have developed [**32**].

MINERAL-BASED POWDERS

Titanium Dioxide Powder

Powders based on titanium dioxide are frequently used to generate latent fingerprints on dark surfaces. The titanium dioxide can be utilized as a powder suspension and suspended in a surfactant to analyze prints on adhesive tapes. TiO2 particles with a surrounding coating, tens of nanometers thick, consisting of Al and Si-rich material with traces of sodium and sulfur, are visible in fingerprint powders as determined by X-ray fluorescence (XRF), analytical transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS), and laser particle sizing. The morphology, thickness, coverage, and composition of the aluminosilicates are the main differences between the white powder formulations and may be connected to variations in the effectiveness of print development. These aluminosilicates are frequently used as anti-caking agents and to improve the adhesion or functionality of certain fingerprint powders [**33**].

HYBRID INORGANIC POWDERS

Silica-Based

New materials for latent fingerprints are still required, even if nanotechnology has given forensic labs a lot of new capabilities. Two key

characteristics of the material should be considered while looking for a new latent trademark developer. The substance should, first and foremost, be simple to identify. It could be luminous, phosphorescent, colorful, etc. Second, it ought to have a variety of affinities for both the substance that the fingermark has been deposited on and the ridges of the mark. Finding a single material that combines the two aforementioned properties is a challenging undertaking. This problem can be solved by using hybrid, organic-inorganic composites. Silica particles are a great basis for this kind of substance. Easy-to-detect components like organic dyes, quantum dots, and others can be added to the silicate matrix, and their surface characteristics can be readily adjusted using organic silane chemistry. Although hybrid silica-based particles with different sizes, shapes, and functional groups have been employed in many other applications, their potential as a new latent fingermark-developing agent has just lately been investigated [**34**]. The three primary categories of hybrid organic–inorganic materials utilized for latent fingermark generation are porous phosphate heterostructures, SiO2-based composites, and SALDI-TOF-MS desorption/ionization facilitation agents [**19**].

Carbon-Based

For matrix-assisted laser desorption/ionization mass spectrometry (MALDI-MS) and its imaging (MALDI-MSI), carbon-based compounds are frequently employed as matrices. However, because of the high background and contamination, researchers have decided not to use carbon-based fingerprint powder (CFP) as a matrix. This study compares CFP to conventional organic matrices and reassesses its compatibility with MALDI-MSI using a high-resolution mass spectrometer (HRMS). Using HRMS, it was simple to separate carbon cluster peaks from relevant fingerprint chemicals. CFP was applied to half of a fingerprint, while conventional organic matrices were applied to the other half for fair comparison. When CFP was utilized as the tritium, the signal-to-noise (S/N) ratios of all the substances under study were either comparable or higher. Furthermore, the trend of S/N ratios was closely followed by chemical image quality. When carbon cluster peaks are well separated by an HRMS, CFP works well as a one-step development and matrix application technique for MALDI-MSI of latent fingerprints [**22**].

FLUORESCENT ORGANIC POLYMER-BASED MATERIALS FOR LFP IMAGING

Fingerprint examinations may produce fluorescence from four sources: 1. Native constituents in latent print residue, 2. Foreign substances picked up by the hand and transferred through deposition, 3. Intentional chemical enhancement, and 4. Substrate (background) fluorescence. The goal of some studies has been to find "native" or intrinsic luminescence in fingerprint residue. Usually mild, this fluorescence is believed to be caused by substances like pyridoxine and riboflavin. Food or drug residue is our example of foreign pollutants that can make fingerprint residue appear luminous. However, fluorescence-producing physical and chemical treatments are usually thought to be the most effective. Chemical reagents, dye stains, and fluorescent powders are frequently used to produce dramatic effects [**35**].

Finally, we talked briefly about carbon dots, a newly developed luminescent substance that is currently being used as a powder for luminescent fingerprints. Although carbon dots are not a common substance in daily life, they can be readily produced using a basic home microwave oven, even from waste items nearby [**14**]. Recently, it has been demonstrated that semiconductor polymer dots are a unique class of ultra-bright fluorescent probes with broad applications in analytical detection. The colorimetric and fluorescent dual-readout capabilities of ninhydrin contained in the near-infrared fluorescent polymer dot matrix allowed for the detection of LFPs on both porous and non-porous surfaces. The dual-readout approach produced fingerprints that showed level 1–3 features with little background interference, great contrast, and high selectivity. For LFP imaging, fluorescent powders composed of a conjugated oligomer with SiNPs were also used [**36**]. Covalently mixed blue-emissive conjugated oligomers with emission quantum yields as high as 62.2% were applied as fingerprint powders to a variety of surfaces, including yellow tapes, glass, stainless steel, and plastic (polycarbonate, PC). Under 365-nm UV light, fluorescent pictures of LFPs on various substrates showed distinct blue fingerprint patterns, retaining a high enough resolution and contrast between the ridges and gaps [**37**].

Using the powder dusting approach, the red-emissive conjugated oligomer with the Carrie epoxy-SiNPs enabled clear imaging of LFPs under 365-nm UV light on a variety of surfaces, including smooth and uneven surfaces, with or without background fluorescence. Compared to hydroxy or amino groups, the addition of epoxy groups to SiNPs may significantly increase their affinity for fingerprints. The fluorescent images of LFPs with a distinct ridge pattern and a high contrast between ridges and furrows demonstrated the imaging potential of LFPs, providing a wealth of information and detailed second- and third-level features [**38**]. Without further treatment, it was confirmed that aggregation-induced increased emission-active conjugated polyelectrolyte could perform high-resolution LFP imaging on a variety of smooth, non-porous substrates. The fingerprint-loaded substrate was simply submerged in the solution for around one minute, then the remaining polymer solution was shaken off and allowed to air dry to complete the LFP development process. High contrast and

selectivity were used to reveal the third-level details in the photos. [**39**]. For the LFP development of stainless steel, a bilayer system based on conjugated and fluorescent polymers was employed. The first layer was electrodeposited onto the surface using polypyrene or PEDOY, and the second layer was electrodeposited onto the first layer using a fluorescent poly (2,2′:5′ 2″-terthiophene). For personal identification, this bilayer system might produce high-definition photographs of the first- and second-level details in both visible and ultraviolet light.

HERBAL DUST POWDERS FOR VIEWING LATENT FINGERPRINTS

Very tiny particles of carbon powder, an inorganic material, are utilized in forensic research; they may have an impact on respiratory health. We might not be able to notice the fingerprints even if the surface is dark or black. In order to see latent fingerprints, this experiment investigated the effects of herbal powders. Before sieving through a 200-mesh filter grille and flicking with a dusting brush while tilting the corner of the transparent glass plate at a 45-degree angle, Turmeric, Monkey Jack, and Wild Turmeric were first dried at 100 degrees Celsius for two hours. We can detect latent fingerprints on the non-porous surface by applying the appropriate quantity of herbal powders. The quality analysis was then computed using the fingerprint quality measurement criteria, and the performance was compared using carbon powder. The minutiae gathered from the inspection systems using the automatic fingerprinting system (Mini-AFIS) revealed the following minutiae analysis values based on the experiments: 21.3 points for Wild Turmeric, 16.7 points for Monkey Jack, and 11.7 points for Turmeric powders [**40**].

EMERGING ORGANIC AND SYNTHETIC FORMULATIONS

Materials doped with rare earth ions have recently attracted attention in the realm of developing forensic fingerprints. It was suggested that spherically formed crystalline calcium molybdate nanophosphors would show little background interference and great contrast on a number of tested surfaces. Under ultraviolet (UV) light, the manufactured nanophosphors' particle sizes ranged from 300 to 500 nm, and they gave off a reddish-green glow. The contrast problem caused by excessive background fluorescence was resolved by using nanophosphors with persistent fluorescence for a while after being exposed to UV light. In the past, a number of other nanoparticles doped with fluorescent compounds to improve contrast have been suggested. Recent years have seen research on the use of natural materials for the same goal as latent fingerprint visualization, in addition to the use of highly manufactured substances. In other cases, anthocyanins and turmeric powder, which are natural fluorescent dye variations, were used to enhance contrast [**34**].

Cellulose, lignin, and silica are the three primary components of rice husk (RH), an agricultural waste that is produced in large quantities in all rice-producing nations. There have been numerous reports of SNP extraction methods from rice husk with differing levels of purity and crystallinity. Numerous methods have been tried, including heat treatments, thermochemical treatments, and alkaline extraction followed by acidic precipitation. The majority of these methods resulted in highly agglomerated, impure silica and nanostructured SNPs. It has recently been shown that spherical monodisperse SNPs made from rice husks are quite effective at creating latent fingerprints on semi-porous and non-porous surfaces. The application of natural dye pigment-doped spherical SNP produced from rice husk to improve the contrast between fingerprint ridges and underlying substrates has been investigated for the first time in this work [**41**].

BIODEGRADABLE AND NATURAL SOURCE POWDERS

Whereas dextran is frequently utilized in pharmaceutical and medical applications, no research employing this biopolymer as a powder component for the developing agent for latent fingerprint visualization has been documented as far as we are aware. In addition to being biocompatible and biodegradable, dextran exhibits non-toxic qualities that shield humans from harmful consequences that frequently occur when commercial chemical and physical procedures are regularly used. This also lowers the total cost of the resulting powder system. Four distinct dextran-based micro powder formulations were made in order to assess how well they could visualize latent fingerprints [**42**]. Interactions between the systems' components were validated by FT-IR analysis. In addition to confirming the produced powdered samples' facile binding to the perspiration and lipid residues found in the latent trace, optical microscopy demonstrated that the samples were uniformly tiny. The findings showed that these new powders based on dextran might be used in addition to commonly used physical techniques for the detection and visualization of latent fingerprints [**43**].

ADVANCED INORGANIC POWDERS

Nano-Enhanced Metal and Mineral Powders

One of the most innovative areas of research is the application of metallic oxide-coated carbon nanoparticles (MOCCNs) in forensic science and water treatment technologies. A promising outcome is the possibility of employing metallic-coated carbon nanoparticles in adsorption procedures and then reusing them in latent fingerprint detection [**44**]. It might be time for a warning. Despite the speed and low cost of utilizing fingerprint powder, there have been growing worries about the potential

for contamination because fingerprint brushes can spread DNA. Forensic scientists and environmental cleanup professionals are being cautioned to be mindful of this potential when examining crime scenes [**9**].

INTRODUCTION OF NANOTECHNOLOGY IN FINGERPRINT POWDER

Technology that works with matter in nanoscale dimensions, which range from 1 to 100 nm, is referred to as nanotechnology. This technology has numerous uses in various scientific domains and is applied at the nanoscale. A new area of forensic science called "nano forensics" makes use of nanoparticles or nano sensors to help with crime investigation. Latent fingerprints have been developed using nanotechnology. Nanoparticles of gold, silver, zinc oxide, silicon oxide, aluminum oxide, carbon, quantum dots, and rare earth metals have all been shown to be highly effective at creating latent fingerprints from a variety of surfaces. For improved outcomes, these nanoparticles have also undergone a number of changes [**45**].

HISTORY OF RECENT ADVANCEMENT IN FINGERPRINT POWDERS AND NANO MATERIALS FOR LATENT FINGERPRINT DEVELOPMENT

Considering their greater sensitivity, resolution, and adaptability to a variety of surfaces, nanomaterials and metal-based powders have become more and more popular in recent advancements in latent fingerprint visualization. Rapid and efficient visualization capabilities have been demonstrated by the development of latent fingerprints on a variety of nonporous surfaces in 1–3 seconds using highly fluorescent, water-soluble cadmium-telluride (CdTe) quantum dots capped with mercaptosuccinic acid. The adhesive side of tapes has also been treated with cadmium-selenide (CdSe) nanoparticle solutions, which increase fluorescence intensity and dramatically lower background noise, improving print clarity [**46**]. To create latent fingerprints on both dry and wet nonporous surfaces, zinc oxide-silicon dioxide nano powders have been created and used as dry powders and in suspension form. These powders are ideal for forensic applications because they exhibit good third-level ridge features with little background staining. Additionally, hydrophobic silica-based nano- and microparticles have been created to provide enhanced adhesion and visualization of both aged and new latent fingerprints on a variety of nonporous surfaces. Because of their special visual characteristics and high affinity for fingerprint remains, metal nanoparticles like gold and silver have been thoroughly researched for fingerprint development [**45**]. to generate high-quality latent fingerprints and enable in-depth analysis of third-level ridge characteristics, gold nanoparticles functionalized with polymer coatings have been employed in combination with photoacoustic imaging. Clear vision on porous surfaces is made possible by the electrostatic interactions of silver nanoparticles with fingerprint remains. Furthermore, when compared to conventional silver-based techniques, gold nanoparticles functionalized with organic ligands and soluble in petroleum ether have demonstrated improved quality and intensity. By creating latent fingerprints on porous and nonporous surfaces, fluorescent cadmium-selenide sulfide nanoparticles functionalized with thiolated porous phosphate heterostructures have shown versatility and increased the use of nanoparticle-based methods in forensic science [**47**]. Latent fingerprint development on nonporous surfaces has been studied using silicon oxide nanoparticles doped with ruthenium complexes. Improved fingermark detection quality without overdevelopment has been demonstrated by optimized nanoparticle-based reagents applied by spray or repeated treatment cycles, suggesting possibilities for operational application at crime scenes. Moreover, surface-enhanced Raman scattering (SERS) reporters embedded in aptamer-functionalized core-shell nanoparticles have been created to enable high-resolution and universal imaging of latent fingerprints. While identifying third-level details, this method enables the recognition of different fingerprint types on a variety of substrates, including fresh and aged prints on smooth, scratched, semiporous, and porous surfaces [**48**].

APPLICATIONS OF THE DEVELOPMENT OF NANOTECHNOLOGY IN THE DEVELOPMENT OF LATENT FINGERPRINTS IN FORENSIC SCIENCE

Latent fingerprints have been developed using nanotechnology. Latent fingerprints are traditionally developed using fingerprint powders and other chemical methods, but these methods have a number of drawbacks, including low visibility, smearing, and an inability to detect old and polluted prints. All of the drawbacks of the conventional techniques currently in use are eliminated by using nanoparticles to create these impressions. Nanoparticles of gold, silver, zinc oxide, silicon oxide, aluminum oxide, carbon, quantum dots, and rare earth metals have all been shown to be highly effective at creating latent fingerprints from a variety of surfaces. For improved outcomes, these nanoparticles have also undergone a number of changes [**45**, **49**].

Environmental and Health Concerns

Like particulate pollution, nanoparticles pose significant health and environmental risks despite their unique advantages due to their small size. Their small size allows them to penetrate biological barriers and interact with various organ systems, which could have unfavorable effects. In animal models, studies have shown that intratracheal instillation of carbon nanotubes can result in severe lung conditions such as epithelioid granuloma,

interstitial and peribronchial inflammation, and lung necrosis. Carbon nanotubes are more dangerous than quartz particles and carbon black [**10**]. Nanoparticles can potentially enter the central nervous system directly through the systemic circulation or olfactory nerve pathways. For example, it has been demonstrated that C60 fullerene nanoparticles cause oxidative stress and glutathione (GSH) depletion when they enter fish brains through the olfactory bulb. Mammal studies have revealed that manganese and carbon nanoparticles build up similarly in the olfactory bulb, pointing to a potential route for nanoparticles to cross the blood-brain barrier. Although this technique may one day be employed for targeted drug delivery, it also raises concerns about possible inflammatory reactions in the brain that require careful examination [**50**].

While fullerenes do not show these effects, in vitro studies have shown that carbon nanotubes can cause platelet aggregation and speed up vascular thrombosis in animal models. This suggests that fullerenes would be safer options for drug delivery systems based on nanoparticles. Furthermore, by triggering pro-inflammatory mediators and causing subsequent organ damage, nanoparticles may be harmful to the gastrointestinal tract and may be a factor in inflammatory bowel disorders. Nanoparticles have the potential to be harmful when consumed since they can enter the bloodstream and spread to different organs [**52**]. Even though these harmful consequences have been thoroughly investigated in vitro and animal models, it is still difficult to extrapolate these results to people because of physiological differences. In order to completely comprehend and reduce any possible health hazards, the use of nanoparticles in human applications, including forensic settings, necessitates careful assessment and further study [**53**]. Furthermore, exposure to nanoparticles like silver nanoparticles (AgNPs), which are frequently utilized in forensic investigations, has sparked worries about how harmful they are to the immunological, hepatic, cardiovascular, neurological, respiratory, and renal systems. Particle size, shape, concentration, and surface chemistry are some of the variables that affect toxicity [**54**].

Safety considerations are made more difficult by the potential for nanoparticle absorption through wounds or torn skin. Given their growing use, it is essential to comprehend and control the toxicological concerns associated with nanoparticles to guarantee safe handling and reduce harmful health impacts during forensic and other applications. Concern over the effects of nanoparticles on the environment is also developing since soil and aquatic life may be impacted by their persistence and bioaccumulation in ecosystems. In order to reduce these dangers, current research highlights the necessity of thorough risk assessments and the creation of safe-by-design nanoparticle solutions [**55**].

DISCUSSION

A balance between scientific advancement and workplace safety is seen in the development of fingerprint development procedures in forensic science. Despite being fundamental and extensively utilized for more than a century, traditional powder dusting techniques pose serious risks to human health and the environment. Due to their fine particle size and potential for inhalation or skin exposure, traditional powders like those containing carbon black or heavy metals have been connected by forensic professionals to respiratory, skin, and eye diseases. These hazards have led to the removal of hazardous formulations, such as powders containing lead and mercury, and have accelerated the hunt for safer substitutes. An important development is the appearance of organic powders made from natural ingredients like turmeric and other plant-based substances. With improved sensitivity, resolution, and substrate compatibility provided by nanoparticles like gold, silver, zinc oxide, and quantum dots, nanotechnology has further transformed fingerprint viewing. Even on difficult surfaces or old residues, these materials can disclose latent prints. But the very qualities that make nanoparticles useful, such as their high reactivity and small size, also raise new issues. According to studies, nanoparticles can cross biological barriers, build up in organs, and cause toxicological effects such as neurological, cardiovascular, and respiratory disorders. There is still a lack of knowledge on the long-term effects of nanoparticle exposure on human health, which makes thorough risk assessment and the use of protective gear for forensic staff necessary. The search for a universal fingerprint powder is still ongoing despite these developments. The substrate, the surrounding environment, and the type of fingerprint residue all influence the ideal formulation. Expert judgment and case-specific selection are, therefore, still crucial. The quality of the original fingerprint development is still a crucial factor in determining the success of identification, even though the inclusion of automated technologies like AFIS has increased analytical accuracy. These powders can be used in environments with abundant resources as well as those with limited resources because they are non-toxic, affordable, and easily accessible. Their ability to provide strong contrast and, in certain situations, fluorescence has reduced occupational dangers and increased the toolkit accessible to forensic investigators.

CONCLUSION

The sensitivity and adaptability of latent print detection have been greatly increased by developments in fingerprint powder technology, which has replaced conventional, frequently dangerous formulations with safer organic and

nanomaterial-based substitutes. Superior imaging and lower toxicity are provided by nanotechnology and natural powders, but they also bring with them new issues with environmental impact, workplace safety, and the absence of a single solution for all surfaces and situations. To optimize forensic reliability while minimizing health and environmental hazards, further research, prudent material selection, and adherence to safety protocols are still necessary. Finding a careful balance between safety, creativity, and real-world forensic science applications will be crucial to the evolution of fingerprints in the future.

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REFERENCES

1. Shakeel M, S.S., A review on fingerprint as an identification tool in the discipline of forensics. Forensic Insights and Health Sciences Bulletin, 2023. 1(1).
2. Hazarika, P. and D.A. Russell, Advances in fingerprint analysis. Angewandte Chemie International Edition, 2012. 51(15): p. 3524-3531.
3. Abuaziz, S.S. and E.M. Hejjaji, Nanotechnology and Conventional Techniques to Detect Latent Fingerprints on Surfaces. International Journal for Research in Applied Science and Engineering Technology, 2022. 10(3): p. 665-669.
4. Monson, K.L., et al., The permanence of friction ridge skin and persistence of friction ridge skin and impressions: A comprehensive review and new results. Forensic science international, 2019. 297: p. 111-131.
5. Abdul Waheed 2025. A scoping review on gender bias in AI-based decision making systems. Integration of Mankind and Society. 2, 2 (Aug. 2025), 42–50. https://doi.org/10.56770/ims2025222
6. Afshan Maqbool, Muhammad Naeem Aamir and Muhammad Naeem 2022. Formulation and evaluation of fast dissolving films embedded with nanoparticles of mirtazapine hydrochloride. Journal of Contemporary Pharmacy. 6, 1 (Jul. 2022), 6–18. https://doi.org/10.56770/jcp2022612.
7. Kanza Amjad, Muhammad Naeem Aamir, Muhammad Akram Choohan, Ume Habiba and Saif Ur Rehman 2022. Preparation and characterization of magnetic nanoparticles loaded with antimicrobial agent. Journal of Contemporary Pharmacy. 5, 2 (Jan. 2022), 53–61. https://doi.org/10.56770/jcp2021522
8. Sultana, H., Rabail Khaliq and Sameera Khurshid 2023. Hybrid nanogel systems' recent development: manufacturing and applications in drug simultaneous delivery associated imaging approach. Journal of Contemporary Pharmacy. 7, 2 (Dec. 2023), 69–76. https://doi.org/10.56770/jcp2023725
9. Riaz, A., Areej Shoukat, Umar Farooq, Zunaira Ashraf, Ishrat Fatima, Talib Hussain, Waqas Arshad and Fatima Abkar Sheikh 2024. Fabrication and characterization of colon targeted ibuprofen nanoparticles. Journal of Contemporary Pharmacy. 8, 2 (Dec. 2024), 96–106. https://doi.org/10.56770/jcp2024825
10. Khizra Mazhar, Aleesha Azhar Khan, Maqbool, A. and Humaira Sultana 2024. A review on ethosomes as nanocarrier for skin delivery of drugs. Journal of Contemporary Pharmacy. 8, 2 (Dec. 2024), 122–131. https://doi.org/10.56770/jcp2024828
11. Singh, A., et al., Role of Nanotechnology in Latent Fingerprint Development, in Friction Ridge Analysis: Applications of Nanoparticles for Latent Fingerprint Development. 2023, Springer. p. 1-16.
12. Cadd, S., et al., Fingerprint composition and aging: A literature review. Science & Justice, 2015. 55(4): p. 219-238.
13. Utzhanova, A., Fingerprint Technology and Sustainable Development. European Journal of Sustainable Development, 2016. 5(4): p. 325-325.
14. Vadivel, R., M. Nirmala, and K. Anbukumaran, Commonly available, everyday materials as non-conventional powders for the visualization of latent fingerprints. Forensic Chemistry, 2021. 24: p. 100339.
15. Kim, E.-J., et al., A pilot study of a new fingerprint powder application method for the reduction of health risk. Analytical Science and Technology, 2019. 32(5): p. 196-209.
16. Sodhi, G., J. Kaur, and R. Garg, Fingerprint Powder Formulations Based on Organic, Florescent Dyes. Journal of Forensic Identification, 2004. 54(1): p. 4.
17. Sodhi, G.S. and J. Kaur, Powder method for detecting latent fingerprints: a review. Forensic science international, 2001. 120(3): p. 172-176.
18. Yamashita, B., et al., Latent print development. The fingerprint sourcebook, 2011. 1: p. 155-222.
19. Leśniewski, A., Hybrid organic–inorganic silica based particles for latent fingermarks development: A review. Synthetic Metals, 2016. 222: p. 124-131.
20. Komal R. Ghodake, S.S.N., A Comprehensive

Review of Fingerprint Development : Exploring Unconventional Powder-Based Techniques. International Scientific Research Journal 2024.
21. Nugroho, D., et al., Fluorophores-rich natural powder from selected medicinal plants for detection latent fingerprints and cyanide. Science Progress, 2023. 106(1): p. 00368504231156217.
22. Hinners, P. and Y.J. Lee, Carbon-based fingerprint powder as a one-step development and matrix application for high-resolution mass spectrometry imaging of latent fingerprints. Journal of forensic sciences, 2019. 64(4): p. 1048-1056.
23. Hansen, D.B. and M.M. Joullié, The development of novel ninhydrin analogues. Chemical Society Reviews, 2005. 34(5): p. 408-417.
24. Drochioiu, G., et al., Ninhydrin-Based Forensic Investigations I. Fingerprints. Int J Crim Investig, 2011. 1(1): p. 37-58.
25. Schulz, M., et al., Visualization of latent biological traces via 5-methylthioninhydrin (5-MTN) staining for forensic DNA typing. Forensic Science International: Genetics Supplement Series, 2011. 3(1): p. e530-e531.
26. Makuwa, P.D., A Critical Analysis of the Format to Obtain Cell Phone Records in Terms of Section 205 of the Criminal Procedure Act 51 of 1977. 2021, University of South Africa (South Africa).
27. Moreno, S., et al., Chemical composition effect on latent print development using black fingerprint powders. Forensic Chemistry, 2021. 26: p. 100366.
28. Bandey, H.L. and A.P. Gibson, Fingerprint development and imaging newsletter: Special edition. HOSDB Investigation, Enforcement and Protection Sector, 2006. 8(6): p. 1-16.
29. Chadwick, S., et al., Comparison of NIR powders to conventional fingerprint powders. Forensic science international, 2021. 328: p. 111023.
30. Friesen, J.B., Activities designed for fingerprint dusting and the chemical revelation of latent fingerprints. Journal of Chemical Education, 2015. 92(3): p. 505-508.
31. Friesen, J.B., Forensic chemistry: The revelation of latent fingerprints. Journal of Chemical Education, 2015. 92(3): p. 497-504.
32. Choi, M.J., et al., An evaluation of nanostructured zinc oxide as a fluorescent powder for fingerprint detection. Journal of Materials Science, 2008. 43: p. 732-737.
33. Jones, B., et al., Nano-scale composition of commercial white powders for development of latent fingerprints on adhesives. Science & Justice, 2010. 50(3): p. 150-155.
34. Rajan, R., et al., Fluorescent variant of silica nanoparticle powder synthesised from rice husk for latent fingerprint development. Egyptian Journal of Forensic Sciences, 2019. 9: p. 1-9.
35. Madhavan, A.A. and B.K. Sharma. Latent fingerprint development with biosynthesized Nano rust. in 2019 Advances in Science and Engineering Technology International Conferences (ASET). 2019. IEEE.
36. Chen, H., et al., Covalent patterning and rapid visualization of latent fingerprints with photo-cross-linkable semiconductor polymer dots. ACS Applied Materials & Interfaces, 2015. 7(26): p. 14477-14484.
37. Lian, J., et al., Recent trends in fluorescent organic materials for latent fingerprint imaging. Frontiers in Chemistry, 2020. 8: p. 594864.
38. Zhang, S., et al., Ultrabright fluorescent silica nanoparticles embedded with conjugated oligomers and their application in latent fingerprint detection. ACS Applied Materials & Interfaces, 2017. 9(50): p. 44134-44145.
39. Ravindra, M., et al., Aggregation induced emission based active conjugated imidazole luminogens for visualization of latent fingerprints and multiple anticounterfeiting applications. Scientific reports, 2021. 11(1): p. 16748.
40. Anuragudom, P., Herbal Dust Powders for Viewing Latent Fingerprints.
41. Rajan, R., et al., Robust synthesis of mono-dispersed spherical silica nanoparticle from rice husk for high definition latent fingermark development. Arabian Journal of Chemistry, 2020. 13(11): p. 8119-8132.
42. Vučković, N., S.D. Dimitrijević, and N. Milašinović, Visualization of Latent Fingerprints Using Dextran-based Micropowders Obtained From Anthocyanin Solution. Adli Bilimler ve Suç Araştırmaları, 2020. 2(2): p. 83-133.
43. Vučković, N. and N. Milašinović, (Bio) polymer-Based Powders As Hidden Treasures in Dactyloscop. Arab Journal of Forensic Sciences & Forensic Medicine, 2024. 6(1): p. 69-80.
44. Fouda-Mbanga, B., et al., Application of Metallic Oxide Coated Carbon Nanoparticles in Adsorption of heavy metals and Reusability for Latent Fingerprint Detection: A Review. Hybrid Advances, 2024: p. 100248.
45. Prasad, V., et al., Role of nanomaterials for forensic investigation and latent fingerprinting—a review. Journal of forensic sciences, 2020. 65(1): p. 26-36.
46. Prabakaran, E. and K. Pillay, Nanomaterials for latent fingerprint detection: a review. Journal of materials research and technology, 2021. 12: p. 1856-1885.
47. Kanodarwala, F.K., et al., Nanoparticles used for fingermark detection—A comprehensive review. Wiley Interdisciplinary Reviews:

Forensic Science, 2019. 1(5): p. e1341.
48. Bhati, K., et al., Sensitive fingerprint detection using biocompatible mesoporous silica nanoparticle coating on non-porous surfaces. Coatings, 2023. 13(2): p. 268.
49. Prasad, V., S. Lukose, and L. Prasad, Emerging forensic applications of nanotechnology. Int J Eng Allied Sci, 2016. 2: p. 1-8.
50. Tripathy, D.B. and S. Pradhan, Nanoparticles induced health hazards through environmental exposure and direct contact. Proceedings of the Institution of Mechanical Engineers, Part N: Journal of Nanomaterials, Nanoengineering and Nanosystems, 2024: p. 23977914241312438.
51. ones, C.S., V.U.M. Nallal, and M. Razia, Nanonutraceuticals in Chemotherapy of Infectious Diseases and Cancer, in Emerging Nanomaterials for Advanced Technologies. 2022, Springer. p. 261-300.
52. ALAtawi, M.K., et al., Silver nanoparticles forensic uses and toxicity on vital organs and different body systems. Advances in Toxicology and Toxic Effects, 2024. 8(1): p. 015-029.
53. Tran, T.-K., et al., Review on fate, transport, toxicity and health risk of nanoparticles in natural ecosystems: Emerging challenges in the modern age and solutions toward a sustainable environment. Science of The Total Environment, 2024. 912: p. 169331.
54. Khan, I., K. Saeed, and I. Khan, Nanoparticles: Properties, applications and toxicities. Arabian journal of chemistry, 2019. 12(7): p. 908-931.
55. Winkler, D.A., et al., Modelling and predicting the biological effects of nanomaterials. SAR and QSAR in Environmental Research, 2014. 25(2): p. 161-172.