IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Eco-Friendly Fingerprint Powders: From Traditional Practices To Future Innovations: A Review

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Abstract: This review paper examines recent eco-forensic approaches for latent fingerprint development, with particular attention to safer and environmentally sustainable alternatives to conventional fingerprint powders. Traditional powders may contain hazardous constituents, including heavy metals, which can pose occupational and ecological risks during routine forensic use. Recent research has therefore focused on non-toxic, biodegradable, agricultural, plant-based, food-derived, biowaste-based, and green-synthesized nanomaterial powders. This review discusses the application of herbal powders, fruit and vegetable peel powders, food-based materials, waste-derived powders, zinc oxide nanoparticles, and fluorescent carbon dots for the visualization of latent fingerprints. Reported studies indicate that many eco-friendly powders can adhere to fingerprint residues and produce clear ridge detail on porous, non-porous, and semi-porous substrates. The review also highlights key challenges, including surface-specific performance, reproducibility, particle-size control, standardization, and the need for wider validation under realistic crime-scene conditions. Overall, the development of fingerprint powders from organic and waste materials supports circular-economy principles by converting low-value residues into useful forensic reagents. Eco-friendly and nanoparticle-assisted powders are presented as safer, cost-effective, and sustainable options for latent fingerprint detection without compromising the reliability of ridge visualization.

Index Terms: Eco-forensics; latent fingerprint detection; eco-friendly fingerprint powder; biodegradable forensic materials; green forensic science.

INTRODUCTION:

Fingerprints are a major part of forensic science because of their uniqueness and longevity as evidence. The importance of fingerprints lies in the fact that every single individual, not even identical twins, have the same fingerprints. This makes fingerprints a great and useful tool for crime identification and linking suspects to crimes [1-3].

Fingerprints are the patterns of ridges and valleys on the fingers. This pattern is formed during fetal development and throughout a person's life. The arrangement of ridges on a person's finger is completely different than everyone. This makes fingerprints even more unique, even among twin [4].

Fingerprints are useful for personal identification because they are unique and do not change throughout a person's life. This makes fingerprints great for identification [5].

Fingerprint evidence can be both convicting and exonerating, which is why it’s a centerpiece of forensic science and is accepted in courts. Also, with modern technology, many old cases can be solved with fingerprints, as they can aid in identifying the victim in a many older cases [6].

When examining evidence left by a crime scene perpetrator, there are methods to visualize prints that are both destructive and non-destructive. Destructive methods are sometimes required to expose latent prints with the trade-off being the destruction of the prints or the surface being examined [7].

In foreign investigation, fingerprint and DNA evidence are both substantial, however, fingerprint evidence is more influential than DNA. This is because DNA is oftentimes absent and more easily degraded or contaminated than prints in certain crime scenes. In certain circumstances, the collection of latent fingerprints is the only physical evidence retrievable [8].

For the case of portable evidence containing latent fingerprints, we are able to use non-destructive methods, however, in the case of non-portable evidence such as surfaces, floors, doors, walls, etc. With the non-portable evidence we are required to use the destructive methods, therefore, we use dusting which is a technique to develop latent fingerprints [9].

Any crime scene, one may find one of the following fingerprint powders: black, grey, white, magnetic, fluorescent, granular, luminescent, nano, biochromatic [10].

Fingerprint powders used to be made of carcinogenic (cancer-causing) and toxic ingredients. Powders that used to be made of the liquid metal used to be associated with the severe effects of lead and mercury poisoning that posed great and serious risk to the health of the forensics [11].

Lead and mercury powders were associated with major injuries to the nervous system, major injuries to the kidneys, and poisoning that lead to death [12]. the fine powders, if inhaled for a long time, increase the risk of developing certain diseases that affect the lungs such as pneumoconiosis, and other disorders that affect the respiratory system [13].

Dust from powders that are made up of heavy metals may ease the risk of developing serious and painful injuries to the skin that may be an allergic reaction. Skin burns and irritation may occur, as well as severe problems that affect the lungs, and eyes [14].

Some examples of powders used at the crime scene are black powders, white powders, grey powders, magnetic powders, fluorescent powders, granular powders, luminescent powders, nano powders, biochromatic powders [15].

Some powders are carcinogenic and pose a great threat to forensic science experts. Powders made with lead and mercury contain toxic substances that can be extremely poisonous to forensic science experts to the extent of having respiratory, dermatological and other systemic health problems [16].

Historically, such powders that contain lead and mercury are powders that can cause mercury poisoning, lead poisoning, neurological disorders, kidney disorders, and often result in genus poisoning death [17].

Such powders, especially in fine particles that can be inhaled, can settle in the lungs and result in pneumoconiosis as a respiratory condition where the fine inhaled dust particles settle in the lungs [18].

Contact with powders containing heavy metals can cause skin dust, including skin allergies, irritation, and burns, especially if inhaled, or if the eyes are exposed to it [19].

Fingerprint powders that are environmentally friendly have shown to be effective in developing latent fingerprints while also being non-toxic and biodegradable, posing no risk to forensic workers and the planet. Data show powders produced from natural sources including clam and worm shells and some plants stick well to fingerprint residue and preserve ridge and minutiae detail while also being effective on a number of surfaces typically encountered at a crime scene such as glass, plastic, metal, and wood. Unlike traditional powders, these powders do not contain hazardous chemicals, thus lowering health risks for users and those around them [20].

An example of these is powder from clam and worm shells. Both types of shells are primarily composed of calcium carbonate and can be processed to a fine dust that will stick to fingerprint residue and not smudge. This dust also provides good contrast and is suited to surfaces of varying composition. Biodegradable and non-toxic powders like these are good substitutes for synthetic powders as they can be used in line with principles of a circular economy by recycling marine waste into forensic powders [21].

ECO-FRIENDLY POWDERS DISCOVERED IN THE LAST DECADES:

Eco-friendly forensic powders can be sorted according to their sources and processing methods. Fully plant-based powders use raw botanicals like neem, turmeric, spinach, hibiscus, and betel leaf as well as some natural dyes. Fruit and peel powders, in turn, only have the dried processed peels and seeds, like pomegranate, lemon, onion, and orange. Edible powders such as gram flour, buckwheat, potato, rice, coffee, and even some baking ingredients are food-based alternatives. As for the more advanced options, nano-particle and non-biochar innovations involve the synthesis of ZnO, and CuO carbon dots and other plant-based nanoparticles for more enhanced forensic applications. Finally, the recycling of wastes and by-products concerns the conversion of industrial and agricultural wastes like coal fly ash, spent coffee, eggshells, clam shells, bamboo leaves, and pistachio shell ash into powders for sustainable materials [22].

CLASSIFICATION:

Broad classification of eco-friendly powder:

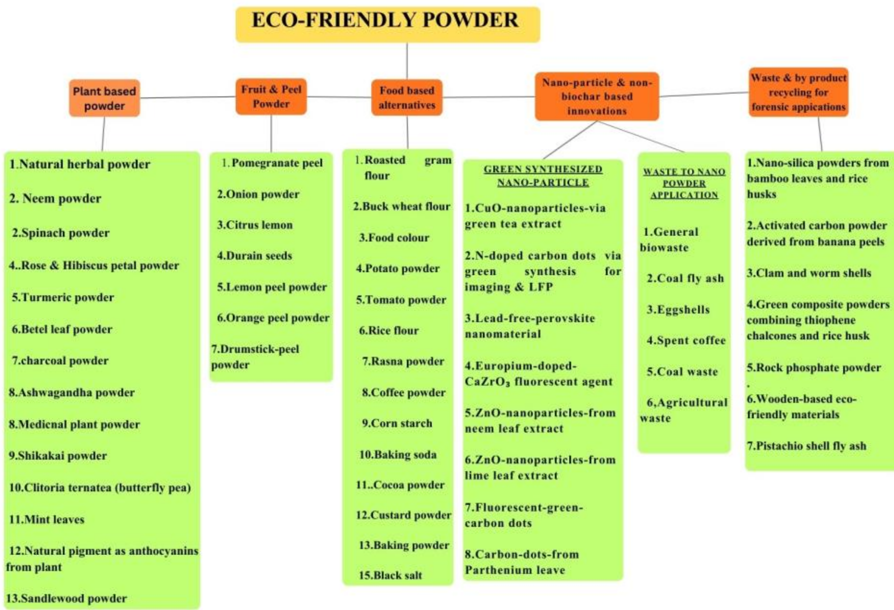

Figure 1. Broad classification of eco-friendly powder sources for latent fingerprint development.

PLANT BASED POWDER

1. From and environmental standpoint, this study examines the herbal powders that can be used for enhancing latent prints. It also examines the herbal powders that can affordably substitute the synthetic powders and determine how the herbal powders and the synthetic powders stimulate the enhancement of ridges of latent fingerprints on different porous and non-porous surfaces. This benefits sustainability and resource accessibility in resource poor settings and facilitates the use of eco-sensitive forensic techniques [23].

2. This is an investigation regarding the application of neem-derived nano-biochar in the retrieval and improvement of weak or damaged latent fingerprints. The nano-biochar possesses pore structures on non-porous and semi-porous surfaces, enabling the adsorption of ridge patterns that traditional powders fail to detect. Its environmentally friendly and biodegradable features that complement the purpose of ecological sustainability are also noted [24].

3. In the case of the investigation of the enhancement of fingerprint detection and contrast, spinach powder, natural dyes, and chlorophyll were analysed on porous and non-porous surfaces. Considering the small footprint, the sustainable technique eco-friendly forensics applications in fingerprint visualization offers are beneficial [25].

4. Finely ground rose and hibiscus petals are another eco-friendly alternative for the detection of fingerprints. While hibiscus and rose powders can be used together for enhanced eco-friendly forensics, both have their benefits-hibiscus for clarity and sticky hold on shiny surfaces, and rose for better colour contrast on non-porous surfaces [26].

5.This study focuses on powders, such as turmeric, betel leaf, and charcoal, to verify their capacity to reveal latent fingerprints on non-porous surfaces. The natural powders are indispensable because they are inexpensive and widespread, and they reduce the dependence on forensic researches that involve harmful minerals [27].

6. Ashwagandha powder seems to be a fingerprint developing agent that can reveal several non-porous and semi-porous surface ridges distinctly, probably to its finely cellular structure and stickiness. This novel method is an environmentally safe and affordable option that fits within eco-friendly forensic science [28].

7. Research on powders from plants shows their incorporation can and is already being used for the latent fingerprint test. This is particularly to enhance the test's contrast through its natural fluorescent compounds on non-porous surfaces,however, it also opens the door for other powders that are safe for the environment and use compared to other fluorescent compounds [29].

8. Shikakai powder purchased commercially is used to develop latent fingerprints with quality marks showing clear ridge patterns across display sheets on porous and non-porous surfaces. As an environmentally sustainable product, this organic powder is safe, affordable, and readily available [30].

9. Derived from 2 plants, Clitoria ternatea (butterfly pea) and Curcuma longa (turmeric), powders as means of fingerprint detection also ridge patterns in superior quality than other powders. This evidence of bordering pigments and high tackiness of the powders to non-porous materials gives further credence to the usefulness of plant powders in forensics [31].

10. This research focuses primarily on the application of pigments, particularly anthocyanins, as plant-based dyes to reveal latent fingerprints. The presence of powders rich with pigments also serves to clarify ridges by increasing contrast on porous surfaces, thus eco-friendliness of the method promotes sustainable practices in forensic science [32].

11. It is evident from the literature review that the natural plant powder (sandalwood) was the substitute sought for, in the commercial chemical powders. This garners high recommendations for its safety, low cost and effectiveness. We mixed sandalwood powder with silver nitrate nanoparticles that enhances fingerprint visibility on non-porous surfaces. This is novel as a non- toxic approach to latent fingerprint detection in forensic investigations. [33]

FRUIT AND PEEL POWDER:

1.The efficacy of the powder of pomegranate peel as an eco-non-toxic fingerprint developer of non-porous materials such as glass and plastic has been investigated. The powder's dye and fine granules have better adhesion to perspiration than other materials and thus enhances the definition and contrast of the ridge. The study emphasizes the powder's potential to be economically sustainable substitute to synthetic powders used in forensics because the material is a waste byproduct. [34]

2.This study focuses on the onion powder as a novel latent fingerprint reagent. Its granule form and strong adhesion to the components of perspiration and oils in fingerprints make onion powder an indispensable fingerprint powder. It allowed the evaluation of porous, non-porous and semi-porous surfaces for clear ridge detail and thus onion powder, being completely biodegradable, is an environmentally friendly and economically viable powder for forensic fingerprint detection. [35]

3. The powder of "Citrus limon (lemon)" has been shown to be an effective fingerprint development medium on a variety of porous and non-porous surfaces due to the reaction of its chemicals with the sweat deposits. The contrast and sharpness of powder provide an eco-friendly and easily accessible substitute reagent especially for forensic purposes, non-toxicity and ease of manipulation being valuable attributes. [36]

4. A group of researchers has shown for the first time the ability of a powder made from the "durian seeds" to develop latent fingerprints. The powder from the extract of the durian seed is an promising forensic substitute because it has produced ridge patterns on a multitude of porous and non-porous surfaces and is eco-friendly, biodegradable, and inexpensive. [37]

5. Fingerprints have been successfully developed from non-porous and porous surfaces by the use of powder made from the peel of lemons and oranges. It has been suggested that to be able to unlock the value of such a resource with their developed ridge patterns and the many colorants, surfaces in resource scarce environments would be able to utilize such powder. [38]

6. The review of the literature describes the moves from chemical fingerprint powder to the more innovative and less harmful, plant-based powders like turmeric and cocoa, and more relevant to this research, durian seed. Hence, it stands to reason, that the powder from the skin of the drumstick would be the leave harmful, inexpensive and readily available option to develop latent fingerprints on porous and non-porous surfaces. [39]

FOOD BASED ALTERNATIVES:

1. This study is concerned with gram flour (sattu powder) and its environmentally friendly, economical and safe powder for revealing latent fingerprints on non-porous surfaces like glass, plastic and steel surfaces. It contains ridge details and is suitable for resource-limited settings [40].

2. Among flours, buckwheat flour is noted to be a powder that is better for the latent fingerprint detection due to its better stickiness and ridge clarity for the porous materials. This powder is also an eco-friendly consumable which makes it a better option for forensic applications [41].

3. Food dyes (blue, orange, etc.) have been used to expose latent fingerprints on non-porous surfaces and have contrasted level 1 and level 2 details. They are non-toxic, and readily available which makes them a good forensic reagent [42].

4. Based on previous studies, powders and ninhydrin seem to be the preferred methods for developing latent fingerprints because they are simple and effective. This is especially the case for dry non-sticky surfaces. Moreover, there is a growing interest in the use of dry household powders as inexpensive forensically useful powders. Some studies show that rice flour, potato flour, gram flour, Rasna, and onion powder show better clarity of ridge details than coffee, mint, and tomato powders on semi-porous and non-porous surfaces. This supports the use of powders for other surfaces to detect clear fingerprints [43].

5. The purpose of this literature review is to assess the availability of household powders, e.g. cornstarch, baking soda, and cocoa powder, to expose latent fingerprints in the absence of commercial powders. It discusses the fact that white and peach powders, that are readily available, do not work well and that they clump. The inconsistency of cocoa and cornstarch powders as well as baking soda, which is ineffective, is discussed. Overall, the review provides evidence for the use of a variety of household powders in the forensic collection of fingerprints to show that they can be used if other resources are not available [44].

6. The review data states the fingerprint powders health effects risks. That is why the health risks of fingerprint powders have been researched, they are inexpensive, non-toxic, and made of common materials and health-safe alternatives. Powders like cocoa, turmeric, custard powder, corn flour, baking soda, salt, and food colouring have been shown to varying degrees of effectiveness in the visualization of latent fingerprints on several porous and non-porous surfaces. The natural powders are inexpensive, readily available, and easy to use. This makes the natural powder application of substitute powders accessible in cases of unavailability of commercial powders. The review as emphasized in the eco-friendly and easily accessible alternative powders, supports their application to forensic studies, both professionals and novices [45].

NANOPARTICLE & NON-BIOCHAR BASED INNOVATIONS:

- **Green synthesized nanoparticles:**

1. This work demonstrates the synthesis of CuO nanoparticles using tea extract as a green approach. The synthesized CuO nanoparticles increased contrast in latent fingerprints on non-porous surfaces which proves the potential of sustainable nanomaterials in forensic fingerprint detection [46].

2. This work focuses on nitrogen doped carbon dots synthesized using green chemistry approaches. The carbon dots synthesized can be used in the imaging and detection of fingerprints using spray methods on non-porous surfaces. The carbon dots have unmatched biocompatibility and are environmentally safe. They can produce images of latent fingerprints in high resolution which can be used in forensics and biomedicine [47].

3. The work presents a lead- perovskite nanomaterial aimed at latent fingerprint detection and counterfeiting. This material has the potential to produce distinct fingerprints with the utilization of ultraviolet light on non-porous surfaces. which connects forensics imaging and security. [48]

4. This work uses europium-doped CaZrO3 as a luminescent material for latent fingerprint detection and white LED applications. The work is capable to illuminating fingerprints on non-porous surfaces which shows a possible combination of forensic and lighting applications. [49]

5. The current study fabricates biogenic ZnO nanoparticles using lime leaves on non-porous surfaces. Eco-friendly biogenic nanoparticles used for forensics bind to latent fingerprints, thus widening the application of such nanoparticles in forensics. [50]

6. Exposure of the eco-friendly approach produced carbon nanomaterials to UV light makes them fluoresce brightly, thus allowing latent fingerprints to be detected on non-porous and semi-porous surfaces. They also enhance the light durability of electronic systems, thereby broadening their target imaging applied in forensic science. [51]

7. The fluorescent carbon powders that derive from leaves of Parthenium are used to detect latent fingerprints, thus eliminating the use of inks. These carbon powders are stable, non-toxic, and capable of producing clear and intricate patterns of fingerprints on non-porous surfaces, which develops eco-friendly forensics. [52]

- **Waste to Nano powder application:**

1.Alternative microwaves-assisted biowaste synthesis methods allowed for the creation of fluorescent-carbon dot nano powders that are sustainable and environmentally friendly. These powders aid in luminescent and efficient fingerprint detection on non-porous surfaces allowing for environmental friendly forensic applications. [53]

2.This study describes the formation of a composite powder combining features of fluoresce and the Rhodamine 6G dye with coal fly ash nanoparticles. This composite is a combination of nano-fluoresce technology and forensic powder enhanced with the technology of fluorescent ridge patterning and precise powdering which improves the visualization of latent fingerprints on non-porous surfaces. [54]

3.This study describes a zero-waste technique which demonstrates the production of biowaste eggshells nano-powders that enhance the visualization of latent fingerprints on multiple porous and non-porous surfaces. This system combines science and sustainability as it improves the technology of fingerprint detection by converting biowaste into a valuable product. [55]

4.This investigation reveals the production of nitrogen doped carbon quantum dots (CQDs) biosynthesized from used coffee grounds through a mild hydrothermal method. These CQDs are uniquely photostable, exhibit profound cyan fluorescence under UV light, and bond strongly to latent fingerprints on smooth (non-porous) substrates like (glass, marble, and metal), facilitating clear visualization of backlit ridge patterns and sweat pore details which are the Forensic features of outstanding CQDs. [56]

5.These studies, especially aim for the implementation of agro-industrial biowaste, mainly natural fruit peels and seeds, to produce fingerprint powders on non-porous surfaces. which is economically advantageous, biodegradable, and addresses waste disposition in eco forensic science. [57]

WASTE AND BY-PRODUCT RECYCLING FOR FORENSIC APPLICATIONS:

1. The research details the recovery and recycling of nano silica powder produced from agricultural by-products, namely, bamboo leaves and rice husks. The recaptured nano silica powders disclosed and lifted latent fingerprints from smooth substrates and supported sustainability since biowaste was converted into a valuable forensic biopolymer. [58]

2. The literature focused on the carbon powder of banana peel describes its ability to disclose latent fingerprints, especially when combined with contrast-enhancing additives like methylene blue. The powder appreciated its non-toxic and environment-friendly attributes, and it was collaborated with distinct ridge pattern formations on porous materials.

3. Fingerprint detection powders made from clam and worm shell grants the friendly sustained substances that demonstrate excellent powder adherence along with clear visibility of ridge details on porous and non-porous surfaces. Their natural abundance and quality as foremost materials suggest them viable profound sustained substitutes for the forensic powders of synthetic origin.

4. Using thiophene chalcones and rice husk lignin, the study develops eco-composite powders that clearly and vividly capture latent fingerprints on non-porous surfaces. The materials are biodegradable and use only the most sustainably harvested materials, presenting rational and environmentally sustainable solutions to forensic fingerprint identification.

5. The objective of the demonstration is to detect easily overlooked fingerprint impressions on various non-porous surfaces using rock phosphate powder. The powder could provide a more environmentally friendly approach to forensic science.

6. The review analyses wood materials as eco-friendly substrates in forensic sampling, such as fingerprinting. Research indicate that these substances are green alternatives for forensic sampling, and that they contain low-cost dextrins that are feasible for sensitive detection on non-porous and semi-porous surfaces.

7. The review demonstrates that there is a growing interest for ecologically sustainable, non-toxic, cheap, and agriculturally beneficial waste streams such as pistachio shell fly ash. There is evidence that these powders are at least as good, if not better, than commercial powders in the detection of fingerprints on several non-porous surfaces. The health and environmental risks associated with these powders are significantly lower. Research demonstrates that fly ash from pistachio shells strongly adheres to the residues of fingerprints and allows for the easy detection of the ridge patterns by using visible or ultraviolet light. This method contributes to the promotion of forensics and the effective use of readily available by-products of agriculture. It presents forensic practitioners with a readily available and environmentally friendly alternative for fingerprint detection.

RESULTS AND DISCUSSION:

Table 1. Reported Eco-Friendly Powders in the Recent Literature

Sr. No.	Reported/Verified Source	Eco-Friendly Powder	Key Findings	Citation
1	Vadivel et al., 2021	Herbal plant powders	Effective on porous & non-porous surfaces	[59]
2	Singh et al., 2023	Neem nano-biochar	Effective on non-porous & semi-porous surfaces.	[60]
3	Yadav et al., 2020	Spinach powder	Effective on porous and non-porous surfaces.	[61]
4	Godara et al., 2022e	Rose and hibiscus powder	Effective on non-porous surfaces.	[62]
5	R et al., 2024g	Turmeric,betel leaf, charcoal	Effective on non-porous surfaces.	[63]
6	Rai et al., 2024	Ashwagandha powder	Effective on non-porous and semi-porous surfaces.	[64]
7	Nugroho et al., 2023	Medicinal plant powder	Effective on non-porous surfaces.	[65]
8	Rajalakshmi & Sabu, 2025	Shikakai powder	Effective on porous and non-porous surfaces;	[66]
9	Patel et al., 2023	Butterfly-pea-and turmeric powder	Effective on non-porous surfaces.	[67]
10	Bārzdiņa et al., 2025	Anthocyanin-rich-plant powders	Effective on porous surfaces.	[68]
11	Suryawanshi et al., 2023	Sandalwood powder	Gives effect on non-porous surfaces.	[69]
12	Darshan et al., 2025	Pomegranate peel	Effective on non-surfaces.	[70]
13	A. Sharma et al., 2025b	Onion powder	Effective on porous, non-porous and semi-porous surfaces.	[71]
14	Camporedondo et al., 2025	Lemon powder	Effective on porous and non-porous surfaces	[72]
15	Elipe et al., 2025	Durian seed powder	Effective on porous and non-porous surfaces.	[73]
16	Elipe et al., 2025	Lemon & orange peel	Effective on non-porous and porous surfaces.	[74]
17	Arul & Singh, 2025	Drumstick peel powder	Effective on porous and non-porous surfaces.	[75]
18	Rai et al., 2023	Roasted gram flour (sattu)	Effective on non-porous surfaces.	[76]
19	Kumari et al., 2024	Buckwheat flour	Effective on multiple porous surfaces.	[77]
20	Venkatesh et al., 2024	Food colouring powders	Effective on non-porous surfaces.	[78]
21	Singla & Sharma, 2020	Rice, potato, gram flour, Rasna	Effective on semi-porous and non-porous surfaces	[79]
22	Way & Henson, 2020	Cornstarch, cocoa and baking soda	Non-effective.	[80]
23	Vadivel et al., 2021	Cocoa, turmeric, custard, corn flour	Effects on porous & non-porous surfaces.	[81]

24	Dubey et al., 2025	CuO nanoparticles from tea extract	Effective on non-porous surfaces.	[82]
25	Ramasubburayan et al., 2024	N-doped carbon dots	Effective on non-porous surfaces.	[83]
26	Liu et al., 2025	Lead-free perovskite	Effective on non-porous surfaces.	[84]
27	Kumar et al., 2024	Europium-doped CaZrO3	Effective on non-porous surfaces.	[85]
28	Sari & Hawari, 2022	ZnO nanoparticles using lime leaves	Effective on non-porous surfaces.	[86]
29	Wang et al., 2022	Fluorescent-carbon nanoparticles	Effective on non-porous and semi-porous surfaces.	[87]
30	Yadav et al., 2024b	Parthenium-based carbon dots	Effective on non-porous surfaces.	[88]
31	Dinake et al., 2021	Biowaste-carbon-dot nano powder	Effective on non-porous surfaces.	[89]
32	Prabakaran & Pillay, 2025	Coal fly ash & rhodamine 6G	Effective on non-porous surfaces.	[90]
33	Said et al., 2021	Eggshell nano powder	Effective on porous & non-porous	[91]
34	Lotey et al., 2025	Coffee waste CQDs	Effective on non-porous surfaces.	[92]
35	Nagar et al., 2022	Agro-waste (peels/seeds)	Effective on non-porous surfaces.	[93]
36	Rajan et al., 2023	Recycled-nano-silica bamboo and rice husk	Effective on non-porous surfaces.	[94]
37	Facci et al., 2025	Banana-peel-activated carbon	Effective on porous surfaces.	[95]
38	Geethanjali & Johnson, 2025	Shell calm & warm powder	Effective on porous & non-porous surfaces	[96]
39	Da Rosa et al., 2022c	Thiophene-chalcones& lignin	Effective on non-porous surfaces	[97]
40	Parkale & Bagul, 2024	Rock phosphate powder	Effective on non-porous surfaces	[98]
41	Millán-Santiago et al., 2021	Wood-based materials	Effective on non-porous and semi-porous surfaces.	[99]
42	Kishankumar K et al., 2025	Pistachio shell fly ash |	Effective on non-porous surfaces	[100]

Interpretative Synthesis of Table 1

Table 1 presents a consolidated overview of eco-friendly powders reported for latent fingerprint development. The reviewed materials can be grouped into four major categories: plant-based powders, food-derived substances, nanoparticle-based powders, and waste-derived or agro-waste materials. Across these categories, the evidence indicates that eco-friendly powders are not limited to a single substrate type; rather, their effectiveness depends on the chemical composition of the powder, particle size, colour contrast, adhesiveness to sebaceous and eccrine residues, and the nature of the receiving surface [59-100].

Among plant-based materials, herbal and botanical powders show considerable promise. Herbal plant powders, spinach powder, shikakai powder, lemon powder, durian seed powder, and drumstick peel powder have been reported to develop prints on both porous and non-porous surfaces [59,61,66,72-75]. Onion powder appears particularly versatile because it has been reported to work on porous, non-porous, and semi-porous substrates [71]. Other plant-derived materials, including rose and hibiscus powder, turmeric with betel leaf and charcoal, medicinal plant powders, butterfly-pea with turmeric powder, anthocyanin-rich plant powders, and sandalwood powder, show stronger surface specificity, with many reports emphasizing non-porous or porous substrates according to the nature of the pigment and powder adhesion [62,63,65,67-69].

Food-derived powders provide another practical group of low-cost forensic reagents. Roasted gram flour, buckwheat flour, food-colouring powders, rice flour, potato flour, gram flour, Rasna powder, cocoa, turmeric, custard powder, and corn flour have been examined as accessible alternatives to commercial powders [76-81]. Their key advantage is availability and user safety; however, the results also show that household materials are not uniformly effective. Cornstarch, cocoa, and baking soda have been reported as non-effective or inconsistent in some contexts, indicating that food-based reagents require surface-specific testing before practical adoption [80].

Nanoparticle-based powders extend the sensitivity and visibility of latent fingerprint development. Green-synthesized CuO nanoparticles, nitrogen-doped carbon dots, lead-free perovskite materials, europium-doped CaZrO3, ZnO nanoparticles, fluorescent carbon nanoparticles, parthenium-based carbon dots, biowaste-derived carbon-dot nanopowder, and coffee-waste carbon quantum dots have been reported mainly for non-porous and semi-porous substrates [82-89,92]. These materials are especially useful where fluorescence, nanoscale adhesion, and enhanced ridge contrast are required. Nevertheless, their routine forensic use still requires standardization of synthesis, particle size, toxicity assessment, storage stability, and reproducible field protocols.

Waste-derived and agro-waste materials form a significant sustainability-oriented category. Eggshell nanopowder, agro-waste peels and seeds, recycled nano-silica from bamboo and rice husk, banana-peel-activated carbon, shell-based powders, thiophene-chalcone and lignin composites, rock phosphate powder, wood-based materials, and pistachio shell fly ash have all been reported as potential fingerprint development materials [90-100]. This category is important because it links forensic practice with circular-economy principles by converting biological, agricultural, and industrial residues into useful forensic powders. Overall, the literature suggests that eco-friendly powders offer a safer and more sustainable direction for latent fingerprint visualization, but comparative validation against standard commercial powders remains essential before large-scale forensic implementation.

CONCLUSION:

Fingerprint analysis continues to be a mainstay of forensic sciences because of its unique ability to distinguish, endure, and reliably recognize people and link them to suspects at varying crime scenes. Although traditional fingerprint powders are effective, they contain harmful and carcinogenic components such as lead and mercury, which pose health risks to forensic employees and ecological threats.

The continued challenge from varying and potentially substrate and forensic situation applications from various natural powders suggests a need to develop standardized formulations. Standardized formulations can provide reproducibility and broaden their applications. Forensic applications in resource limited situations should be a focus of future research and innovation.

Ultimately, the most significant and encouraging change for future crime scene investigations is the development of non-toxic, natural, and nano-enhanced fingerprint powders. This innovation supports safer and more eco-friendly fingerprinting techniques in forensic science.

ACKNOWLEDGEMENT:

The author would like to extend a heartfelt thank you to JSPM University, Faculty of Health Sciences, School of Behavioural and Forensic Sciences, for providing the essential facilities and academic support that made this work possible. A special shout-out goes to Ms. Pallavi Jaiswal for her invaluable guidance, encouragement, and unwavering support throughout this journey. Her expert insights and constructive feedback played a crucial role in bringing this review to fruition. The author also appreciates the cooperation and assistance of the faculty members and laboratory staff at the School of Behavioural and Forensic Sciences during the work.

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