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REVIEW

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A comprehensive review on the detection of latent fingermarks using carbon dots

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Abstract

Background Fingermarks are one of the oldest, reliable, and universally accepted evidence found on the crime scene. They can be used to link suspect with scene of crime and weapon of offence. Fingermarks are frequently used to investigate criminal cases and identify missing persons and criminals.

Main text Conventional methods such as cyanoacrylate fuming, iodine fuming, ninhydrin, silver nitrate, small particle reagent, and powder dusting are routinely used to detect and develop latent fingermarks on various surfaces of forensic importance. However, these methods suffer several limitations including poor contrast, low sensitivity, background interference, and low specificity. To overcome these limitations, nowadays, nanoparticles have gained importance in the development of latent fingermarks. In this review, we focus on the carbon dots (CD's) nanomaterial for the development of latent fingermarks. CD's have superior fluorescence performance, color tuneability, and low synthesis cost and are non-toxic. The color and intensity of luminescence of CD's depend on its morphology and synthesis method. CD's can be used either in solid or solution form to develop latent fingermarks on the various porous and nonporous surfaces.

Conclusion CD's are potentially a good candidate to develop latent fingermarks on wide range of porous and nonporous items of forensic importance. The fingerprints developed with CD's show excellent contrast and resolution. Their small size, biocompatibility, facile and low-cost synthesis, and color tuneability can be successfully utilized to overcome the limitations of the conventional methods.

Keywords Latent fingermarks, Nanoparticles, Carbon dots, Synthesis, Powder dusting, Fluorescence

Background

Fingermarks are a feature unique to each individual. Due to this uniqueness and the permanent nature, they can be employed to determine the identity of person and, in case of a crime, provide vital clues about the identity of a suspect. Fingermarks are one of the universally accepted, oldest, and reliable evidence found on various kinds of items recovered from the scenes of crime. Individualization from fingermarks is based on the relative arrangement of Galton details, presents on fingertips, and considered as confirmatory in nature beyond any doubt (Champod et al. 2016; Ramotowski 2012). Fingermarks are the result of the perspiration residues released from the pores on the friction ridge skin of the digits. These prints are referred to as latent fingermarks, as they are generally invisible to the naked eye (Knowles 1978; Ramotowski 2012; Thomas 1978). Apocrine, eccrine, and sebaceous glands are the primary source of natural secretions from fingers. Numerous eccrine glands are present on the palms of hands which produce colorless sweat. It contains approximately 0.5% organic, 0.5% inorganic,

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and 99% water contents. Eccrine sweat consists of amino acids, proteins, sugars, choline, lactic acid, creatinine, urea, and uric acid, whereas sebaceous sweat consists of fatty acids, glycerides, sterol esters, squalene, and wax esters (Bumbrah 2017; Bumbrah et al. 2016; Kuno 1934; Scruton et al. 1975).

Various kinds of optical, physical, and chemical methods are commonly used alone or in a defined sequence to visualize latent fingermarks or to enhance the contrast and quality of developed fingermarks on diverse kinds of surfaces. Optical methods are nondestructive and employ electromagnetic radiations of the appropriate frequencies to reveal latent fingermarks. Physical methods involve the physical interaction of reagent or powder with residues of latent fingermarks. Chemical methods involve the transformation of a specific component of perspiration into a colored byproduct through a series of the chemical reaction. Selection of the method depends on condition (wet or dry), color (light, dark, multicolored), texture (smooth and rough), and nature (porous, semi-porous, nonporous) of surface on which the latent fingermark is deposited (Bumbrah 2016; Bumbrah 2017; Bumbrah and Rawat 2019; Bumbrah et al. 2016; Bumbrah et al. 2019; Bumbrah et al. 2022; Levin-Elad et al. 2017; Palak and Bumbrah 2019; Ramotowski 2012).

Main text

Powder dusting, ninhydrin (NIN), 1,8-diazafluoren-9-one (DFO), 1,2-indanedione (IND), cyanoacrylate fuming, iodine fuming, oil red O (ORO), physical developer (PD), and small particle reagent (SPR) are frequently used conventional methods to develop latent fingermarks on various types of surfaces of forensic importance. These methods usually involve the interaction of fingerprint composition with amino acids, fatty acids, lipids, and/or proteins present in residues of latent fingermarks (Champod et al. 2016; Ramotowski 2012). Powder dusting is the oldest physical method to detect fresh latent fingermarks on dry, smooth, nonporous surfaces. This method is incapable of developing aged and wet latent fingermarks and requires experienced hands and use of toxic powder formulations (Sodhi and Kaur 2001). NIN, DFO, and IND are chemical methods of developing fresh and aged latent fingermarks on dry, porous surfaces. However, these methods are not suitable for developing wet latent fingermarks, require posttreatment steps to enhance the contrast of developed prints, and prone to destroy the writings present on the surface of paper substrates due to the presence of toxic solvents in their working formulations (Bumbrah and Rawat 2019; Jasuja and Singh 2009; Ramotowski 2012; Sodhi and Kaur 2001). Cyanoacrylate fuming is the most suitable chemical method to develop latent fingermarks on dry and wet nonporous surfaces. But this method suffers from some practical limitations including poor contrast, use of toxic cyanoacrylate, and pre- and posttreatment procedures (Bumbrah 2017). Iodine fuming is the simplest and rapid method to develop latent fingermarks on porous surfaces. However, this method is not suitable for developing latent fingermarks on wet surfaces. The chief limitation of this method is that developed fingermarks are not permanent in nature and fade with passage of time or on exposure to heat (Jasuja and Singh 2009). ORO and PD methods are frequently used to develop latent fingermarks on wet and porous surfaces. Extensive use of toxic solvents, laborious multistep development process, and limited contrast are some of disadvantages associated with these methods (Bumbrah et al. 2019; Chung et al. 2019; Sodhi and Kaur 2016). SPR method is used to develop latent fingermarks on wet, nonporous surfaces. However, lack of fluorescence, poor contrast, and inability to develop identifiable fingermarks on multicolored surface are major limitations of conventional SPR formulation (Bumbrah 2016).

Most of the limitations of these conventional fingermark development techniques can be resolved by using quantum dots (QDs). QDs are ultrasmall size (usually 1–10 nm) semiconducting nanomaterials that are quantum confined. QDs are characterized as zero-dimension species. QDs exhibit size unique optical properties due to tunable band gap and quantum confinement effects. Depending on their size and composition, QDs give strong fluorescence under UV, VIS, or NIR irradiation. Size-tunable QDs significantly improve the resolution of technique than conventional methods used to develop latent fingermarks (Chung et al. 2019; Ramotowski 2012). It is observed that only three kinds of QDs (CdTe, CdS, and CdSe) constitute 80% of the publications on their application in latent fingermark development (Kanodarwala et al. 2019). Menzel et al. (2000) reported the first use of QDs in developing latent fingermarks. Photoluminescent CdS/dendrimer nanocomposites solution was used to enhance the contrast of cyanoacrylate fumed fingermarks on aluminum foil and polyethylene. In a similar study, Jin et al. (2008) used photoluminescent CdS/PAMAM quantum dots (CD-24), in solution form, to improve the quality of cyanoacrylate fumed fingermarks on tin foil. Dilag et al. (2009) used chitosan encapsulated photoluminescent CdS quantum dots (CD-19) suspension for the detection of latent fingermarks on aluminum foil. Liu et al. (2010) used water-soluble multicolored fluorescent CdTe quantum dots to develop fingermarks on sticky side of adhesive tapes. Gao et al. (2011) used fluorescent positively charged CdTe QDs (CD-16) for developing fingermarks on aluminum foil, marble, glass, polymer, rubber, and transparent polypropylene. It was observed that positively charged CdTe QDs shows superior detection capability than negatively charged CdTe QDs.

Carbon dots (CD’s), also called as carbogenic nanoparticles, are carbon-rich nanomaterials having a size of less than 10 nm. Due to its small size, they are quantum confined which makes them luminescent when irradiated with UV light. The color and intensity of luminescence depend on the diameter, shape, and surface state of CD’s (Tuerhong et al. 2017).

In recent years, the utility of CD’s, as a fingermark reagent, in developing latent fingermarks has increased due to their high aqueous solubility, color tuneability, ease of functionalization, and low toxicity. Rich sources of carbon such as amino acids, citric acid, graphite, mushrooms, starch, or peels of pomelo and orange are frequently used as precursors in the synthesis of CD’s due to their easily availability and cost-effectiveness (Li et al. 2016; Lu et al. 2012; Prasannan and Imae 2013). Various methods such as electrochemical, microwave, pyrolysis, and solvothermal are routinely used to prepare CD’s (Jin et al. 2008; Liu et al. 2019a, b; Ren et al. 2018; Wang et al. 2014; Wang et al. 2018a, b, c). However, hydrothermal method is the most used method to synthesize high-quality CD’s. It includes the use of high temperature and high pressure to carbonize the precursors (Li et al. 2019; Milenkovic et al. 2019; Tang et al. 2019).

The study was preliminary in nature, and no information about types of fingermarks and substrates tested was provided. Therefore, the results of this study can be considered as subjective in nature and do not prove the potential utility of CD’s as fingermark reagent. Since this first report, several reports on the use of CD’s as latent fingermark development agents have been published as we shall describe in detail in this mini-review. However, as shall be seen from the studies, the current technology is not universal, and different types of CD’s-based reagents have been reported that are appropriate for different conditions and surfaces. The aim of this report is to make the reader aware about the progress made in the field, to compare the various types of CD’s, and to discuss potential ways that this technology may be improved towards the development of a universal and affordable reagent that may be used to develop latent fingermarks with a quick response time on maximum types of surfaces.

Applications of carbon dots in developing latent fingermarks

Li et al. (2016) used starch-based fluorescent CD’s (CD-1) to develop fresh and aged (1 year old) fingermarks on aluminum foil, coin, copper foil, zinc sheet, iron sheet, and stainless ruler. The developed fingermarks produce high contrast, color tunability, and blue fluorescence when irradiated with 365-nm UV light. The use of starch-based fluorescent CD’s over cyanoacrylate fuming, iodine fuming, and titanium dioxide powder was suggested due to high sensitivity, better contrast, less background interference, and intense fluorescence produce by these CD’s. CD-1 are useful for developing fingermarks on dark and multicolored surfaces. Fernandes et al. (2015) used fluorescent silica-based CD’s (CD-2) to develop fresh latent fingermarks on metal, glass, and soft drink bottle foil. These CD’s possess color tuneability and are non-toxic. The developed fingermarks appear blue, green, or red when irradiated with violet, blue, and green light and f background surfaces as shown in Fig. 1 (a-e). Automated fingerprint identification system (AFIS) was used to evaluate the quality of developed fingermarks in a quantitative manner, and it was observed that 71 minutiae were detected and matched in fingermarks developed with CD-2. In contrast, only 65 minutiae were detected and matched in fingermarks developed with conventional white powder as shown. Therefore, the use of silica-based CD’s over conventional white fingermark powder was recommended due to enhanced image quality and optimal contrast on radically different backgrounds.

Prabakaran and Pillay (2020) used cost-effective, non-toxic, fluorescent nitrogen functionalized CD’s coated zinc oxide nanoparticles (N-CD’s/ZnO NPs) (CD-3) to develop fresh and aged (4 weeks old) latent fingermarks on aluminum-based surfaces such as rod, foil, and sheet and compact disc, black mat, magazine paper, iron disc, and white marble. The developed fingermarks show high contrast and blue fluorescence when irradiated with 365-nm UV light. It is strongly recommended the use of nitrogen functionalized CD’s coated zinc oxide nanoparticles to develop the latent fingermark on these surfaces over commercially available titanium dioxide and zinc sulfate powders. Zhao et al. (2018) used fluorescent green-emitting CD’s (CD-4) to develop fresh and aged (60 days old) latent fingermarks on glass, transparent tape, sealed bag, and tin foil. CD-4 were also used to successfully develop 4-day-old latent fingermarks on moist tin foil. Algarra et al. (2019) synthesized fluorescent P-doped carbon nanopowder (CD-5) using 1,3-dihyroxyacetone and diphosphorus pentaoxide. CD-5 were used to develop fingermarks on Euro banknote, smart phone screen, magnetic band, and metallic surface of credit card, and clear, identifiable prints were developed showing high contrast on these surfaces without any background noise as shown in Fig. 2 (a-e).

Tang et al. (2019) used orange-emitting CD’s (CD-6) to develop fresh and aged (120 days old) latent fingermarks on silicon wafer, tape, coin, optical disc, cardboard, plastic food package, glass, and beer cans. This method

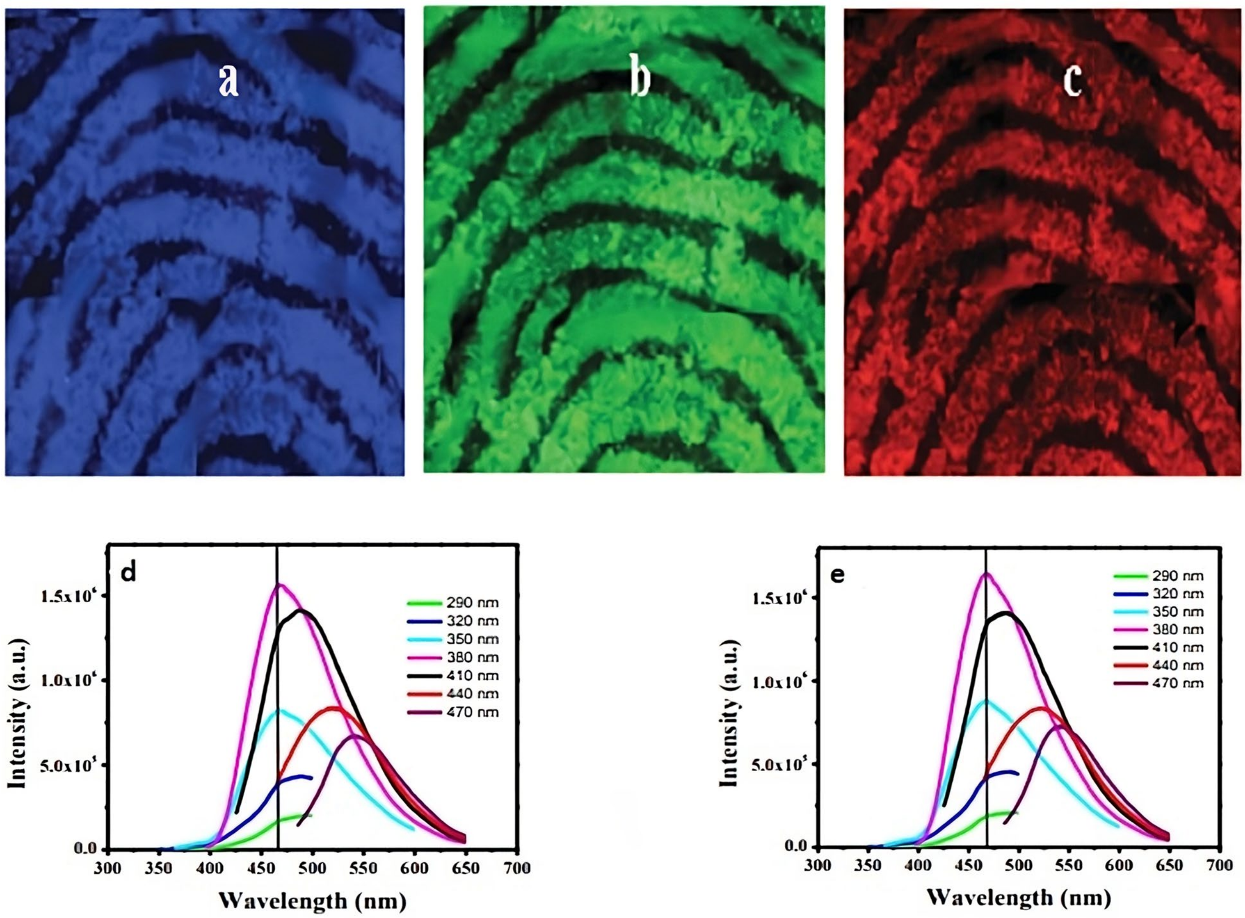

Fig. 1 Fluorescence microscopy images of fingermarks developed with hybrid nanopowder (0.7 wt% C-dot—silica) on a glass slide under (**a**) violet, (**b**) blue, and (**c**) green excitation wavelength. A number of fluorescence images (captured at 100 magnification) have been merged via the Photoshop software to create the larger images displayed. Photoluminescence spectra (under different excitation wavelengths) of aqueous dispersions containing (**d**) 13 µg/ml CD's and (**e**) 13 µg/ml CD's in the presence of (150 times higher concentration) silica nanoparticles (Fernandes et al. 2015) (Reproduced from Chem. Commun., 2015, 51, 4902 with permission from the Royal Society of Chemistry)

is sensitive, efficient, and relatively fast (only 10 s are required) to develop fingermarks on these surfaces. The composition is non-toxic, biocompatible, stable, and able to develop bright and fluorescent fingermarks on multicolored surfaces.

Li et al. (2018) developed and used cost-effective, fluorescent carbon dots/ZIF-8 (CD-7) powder to detect fingermarks on plastic and glass. The formulation can be successfully used to develop fluorescent fingermarks on multicolored and surfaces with strong background. The developed fingermark shows tunable color with different excitation wavelengths, and therefore, multicolored imaging of latent fingermarks can be done.

Li et al. (2017) prepared and used fluorescent silica-based CD's (CD-8) to develop fresh and aged (3 months old) latent fingermarks on aluminum foil, marble, wood, ceramic tile, plastic, stainless steel, and transparent tape. CD-8 are biocompatible and show tunable visible emission in both solid and aqueous state. The developed fingermarks show high contrast, strong photoluminescence, photostability, and second-level ridge details.

Zhao et al. (2017) synthesized the silane-functionalized carbon dots (Si-CDs) (CD-37) that exhibited adjustable fluorescence depending on the wavelength of excitation. The study determined that CDs/SiO_2 nanoparticles shown remarkable selectivity and sensitivity in detecting fingermarks on several realistic substrates, including glass, aluminum foil, plastic bags, medication packaging, and leather. Clear and distinct fingermarks with well-defined ridges and strong contrast may be seen when illuminated with a 415-nm light source with a yellow filter.

Jiang et al. (2018) used white-emitting CD's (CD-9) to develop eccrine and sebaceous-rich latent fingermarks on glass. The second-level ridge details can be seen in the developed fingermarks on exposing them to UV light of 365-nm wavelength. Deng et al. (2019) used

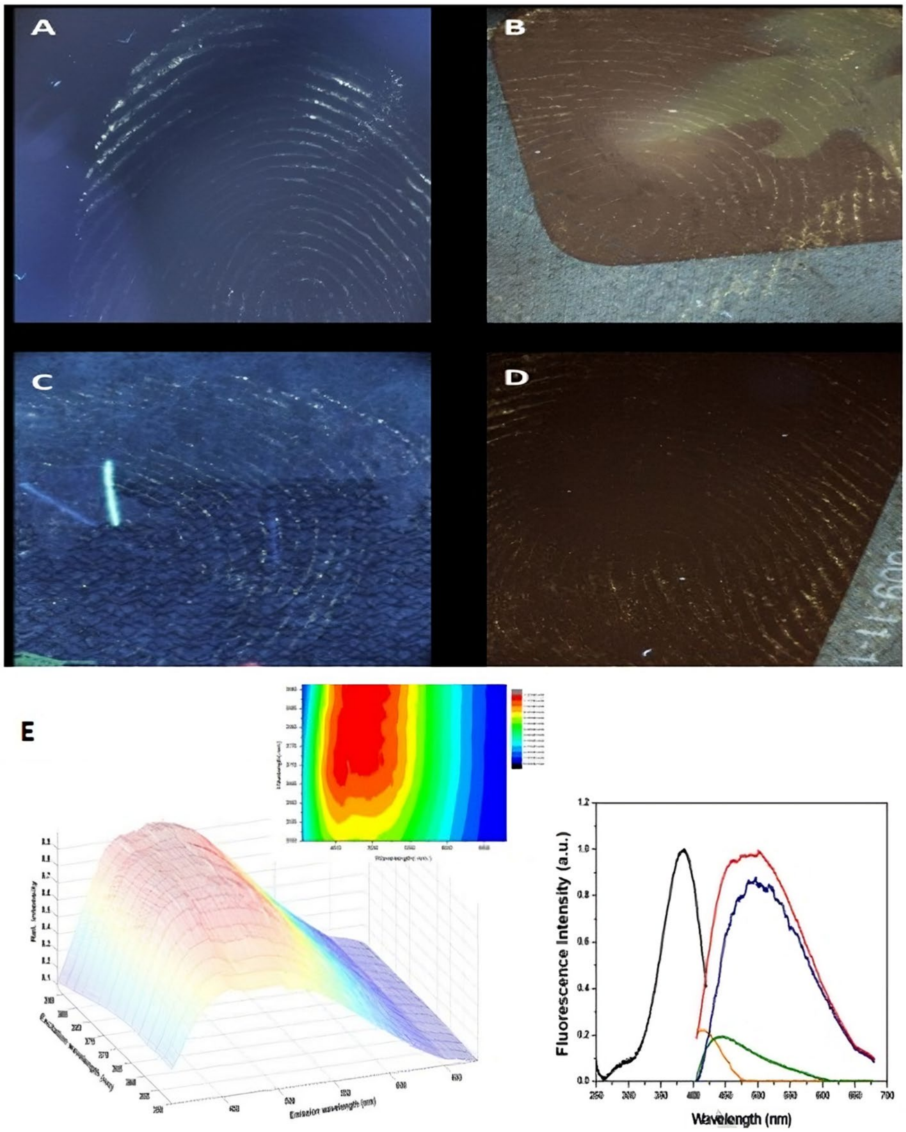

Fig. 2 Latent fingermark images based on P-CD's nanoparticles on different surfaces of (**A**) LCD screen of a smartphone, (**B**) metallic symbol of Visa credit card, (**C**) 20 Euro banknote and (**D**) magnetic band of credit card, (**E**) excitation-emission landscape for the raw spectra of P-CDs and corresponding contour plot shown in inset and excitation spectrum of P-CDs for the emission at 480-nm (black) and matching emission spectrum (red) along with the estimated emission profiles for P-CDs at 416/446/495 nm (orange, green, and blue) (Algarra et al. 2019) (Talanta, 2019, with permission from Elsevier)

blue- and orange-emitting nitrogen-doped CD's (CD-10) to develop latent fingermarks on glue film. The use of CD-10 over conventional methods to develop latent fingermarks is suggested due to their ease of use, good dispersibility, and non-toxicity. Chen et al. (2017) synthesized and used red emissive fluorescent CD's (CD-11) to develop fingermarks on leather, glass, plastic, and aluminum foil. It was observed that CD's were located at the edges of fingermarks and were developed due to electrostatic interaction between CD's and residues of latent fingermarks. The formulation is effective in reducing ACQ effect and background fluorescence interference. It is an effective, rapid, and portable method to detect fingermarks. Milenkovic et al. (2019) used fluorescent nitrogen-doped CD's (CD-12) to develop latent fingermarks on plastic bags and steel tweezers as shown in Fig. 3 (a-c). It was observed that fingermarks were developed due to electrostatic interactions between negatively charged CD's and positively charged components of latent fingermark residues. CD-12 were reported to be biocompatible

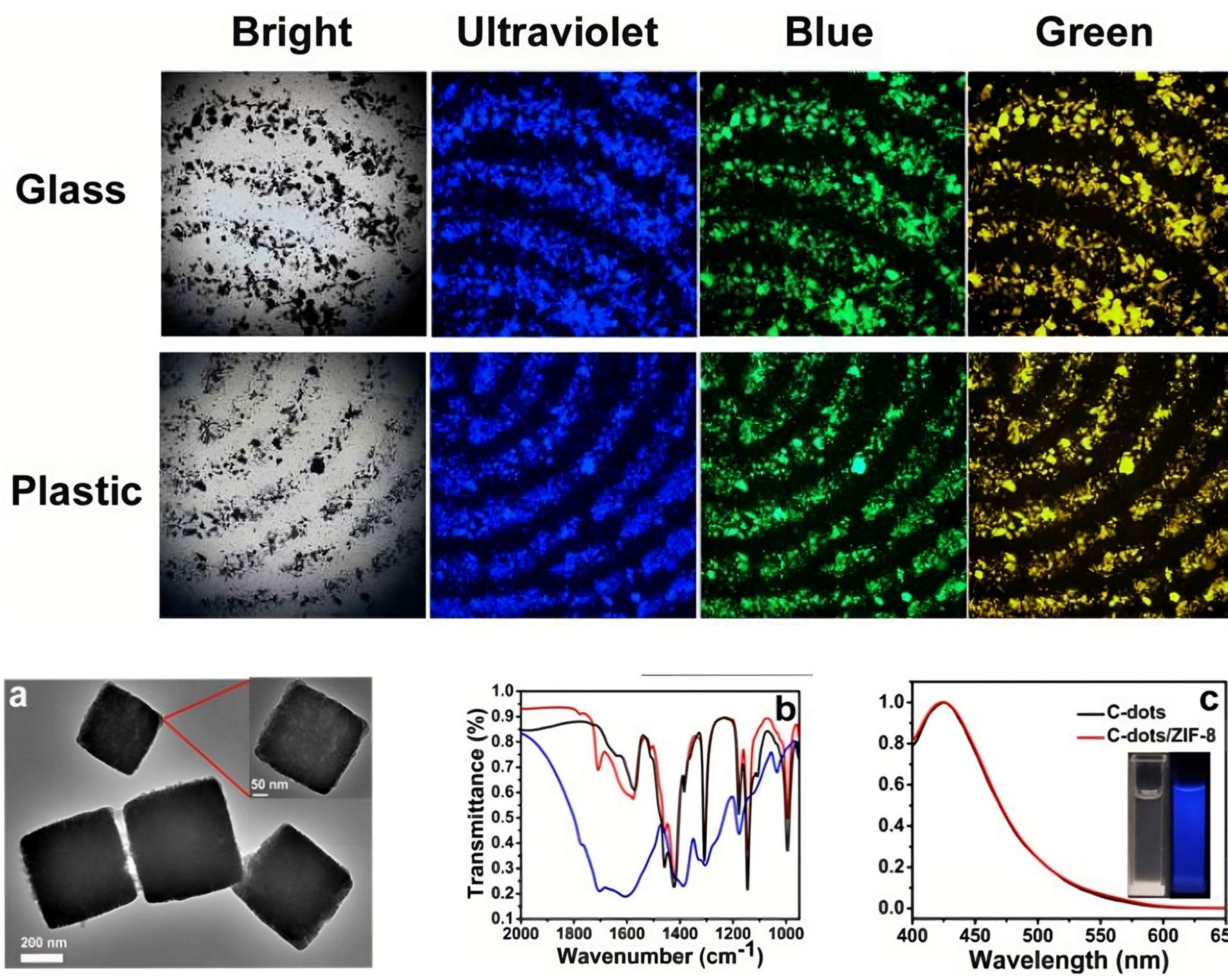

Fig. 3 Fluorescence microscopy images of latent fingermarks developed with CD's/ZIF-8 fluorescent powder on a glass and plastic. **a** TEM images of CD's/ZIF-8 fluorescent powder. **b** The FTIR spectrums of the CD's/ZIF-8 fluorescent powder (red), ZIF-8 (black), and CD's (blue). **c** Normalized fluorescence emission spectra of CD's and CD's/ZIF-8 fluorescent powder under the excitation wavelength of 360 nm and inset photographs showing these CD's/ZIF-8 fluorescent powder under natural light (left) and 365-nm UV light illumination (right) (Li et al. 2018) (Reproduced from CrystEngComm, 2018, with permission from the Royal Society of Chemistry)

and non-toxic. Ren et al. (2018) used nitrogen-doped fluorescent CD's (CD-13) to develop latent fingermarks on silicon wafers. The formulation was reported to be biocompatible, and the developed fingermarks show third-level ridge details. Li et al. (2019) synthesized and used hollow orange fluorescent CD's (CD-15) to develop latent fingermarks on glass. The developed fingermarks show stable orange-colored fluorescence with negligible background fluorescence interference.

Liu et al. (2019a, b) synthesized fluorescent nanofibrillated cellulose-based CD's (CD-16) coated paper to detect fresh and aged (21 days old) latent fingermarks on cloth, glass, wall, paper, and rubber. This method of developing latent fingermarks was highly efficient and independent of environment of substrates. The developed prints exhibit excellent fluorescence when illuminated with UV light source, and third-level ridge details can be seen. It was observed that residues adhere to coated paper through hydrophilic effect, capillary effect, and nonspecific adsorption effect. Improved contrast, sensitivity, accuracy, and low background noise are major merits of this method of fingermark development. The use of CD-16 over cyanoacrylate fuming and iron oxide-based SPR composition is suggested to develop latent fingermarks on rubber. In addition to this, the use of coated paper over commercial adhesive tape-lift method to develop high-quality fingermarks is recommended. Bahadur et al. (2019) synthesized and used multicolored fluorescent nitrogen-doped cationic CD's (CD-17) to develop fingermarks on aluminum foil, glass, paper, optical mouse, metallic alloy, and porcelain. The synthesized cationic CD's can be used to perform quantitative and qualitative analysis of fingermarks using multicolor fluorescence emission of cationic

CD's. These CD's show excitation-dependent multi-fluorescence. The developed fingermarks show third-level ridge details. Due to their additional superior solid-state optical properties, improved contrast, and biocompatibility, use of cationic CD's over traditional methods of latent fingermarks development was suggested. These cationic CD-17 are used as fluorescence-based imaging probes and therefore do not react or contaminate the evidence at crime scene. Wang et al. (2018a, b, c) synthesized and used self-quenching-resistant CD's (CD-18) to develop latent fingermarks on plastic, glass, tin foil, and weighing paper. It was observed that size and photoluminescent properties of these CD's depend on the concentration of precursors. These CD's effectively overcome or suppress the ACQ effect and emit tunable solid-state fluorescence. The developed fingermarks show excellent color tunability, and second-level ridge details can be clearly seen as shown in Fig. 4 (a-e). Dilag et al. (2015) used non-toxic, fluorescent poly(dimethylacrylamide)-doped CD's (CD-19) to develop fresh and aged (2 weeks old) latent fingermarks on aluminum foil. Wang et al. (2014) used non-toxic, water dispersible, fluorescent CD's (CD-20) to develop latent fingermarks which give the blue color prints under the photoluminescent property. Various fingermarks collected from volunteers in this lab were developed successfully and clearly identifiable; this shows the potential of CD-20 for the individual identification. Zhai et al. (2019) used montmorillonite-doped green-emissive CD's (CD-21) to develop latent fingermarks on plastic, glass, and tin foil as shown in Figs. 5 (a-c). It was observed that uniform dispersion and confinement of green CD's into montmorillonite efficiently prevent the cluster-induced solid-state luminescence quenching of green CD's and thereby improves their fluorescence. It was also observed that in an organic solvent, chloroform did not affect the photoluminescent properties of these CD's. The developed fingermarks show green fluorescence under UV light without background staining. CD-21 were reported to be biocompatible, non-toxic, and exhibit excellent photo- and thermal stability. Thongsai et al. (2017) used fluorescent multifunctional nitrogen-doped CD's (CD-14) to develop fingermarks on glass slide as shown in Fig. 6 (a-l).

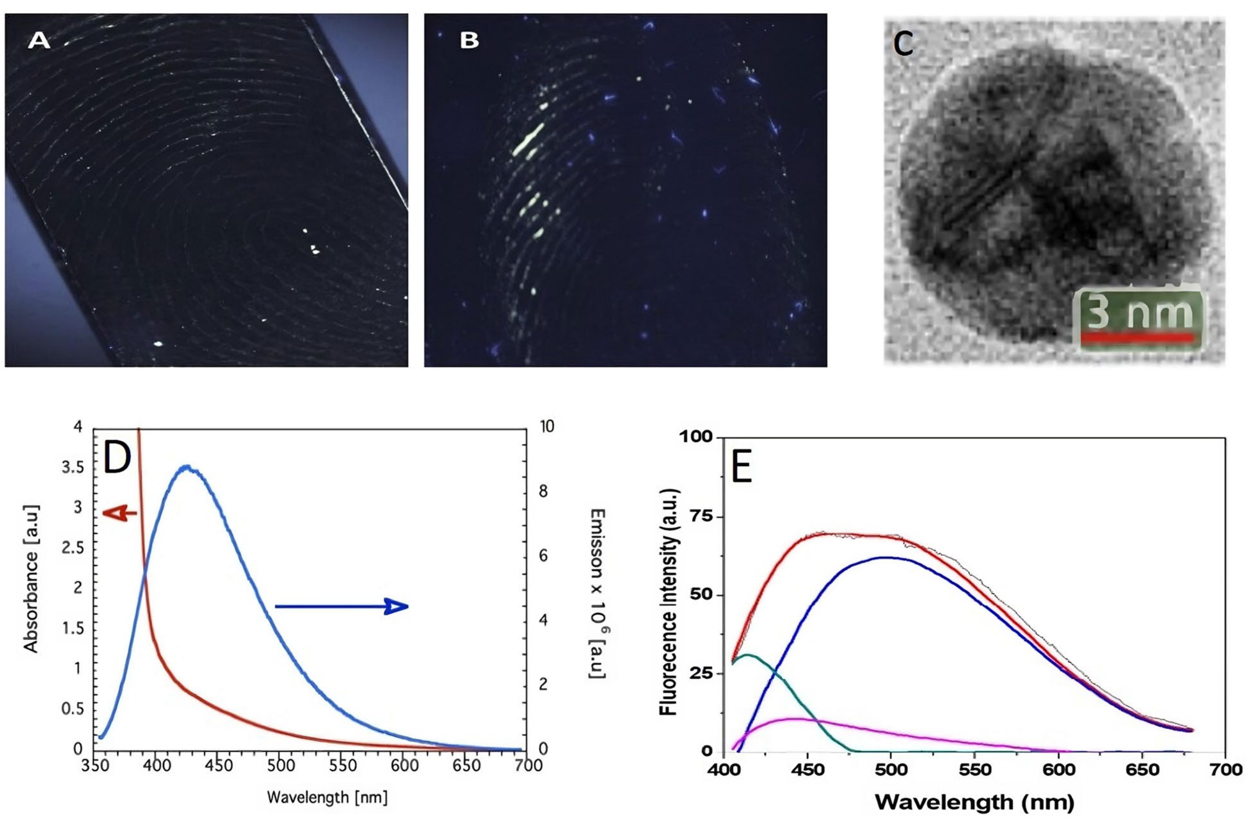

Fig. 4 Latent fingermark images based on N-CD's nanoparticles on tested surfaces of (**A**) a metal tweezers and (**B**) a regular plastic PET bag, (**C**) HRTEM, (**D**) UV absorbance and emission spectra of N-CD's. (**E**) Estimated emission contributions of N-CQDs nanoparticles at 411 (green), 450 (pink), and 495 (blue). Emission spectra (black) and estimated emission spectra (red) of N-CQDs under excitation 350 nm (Milenkovic et al. 2019) (Carbon 144, 2019, 791-797 with permission from Elsevier)

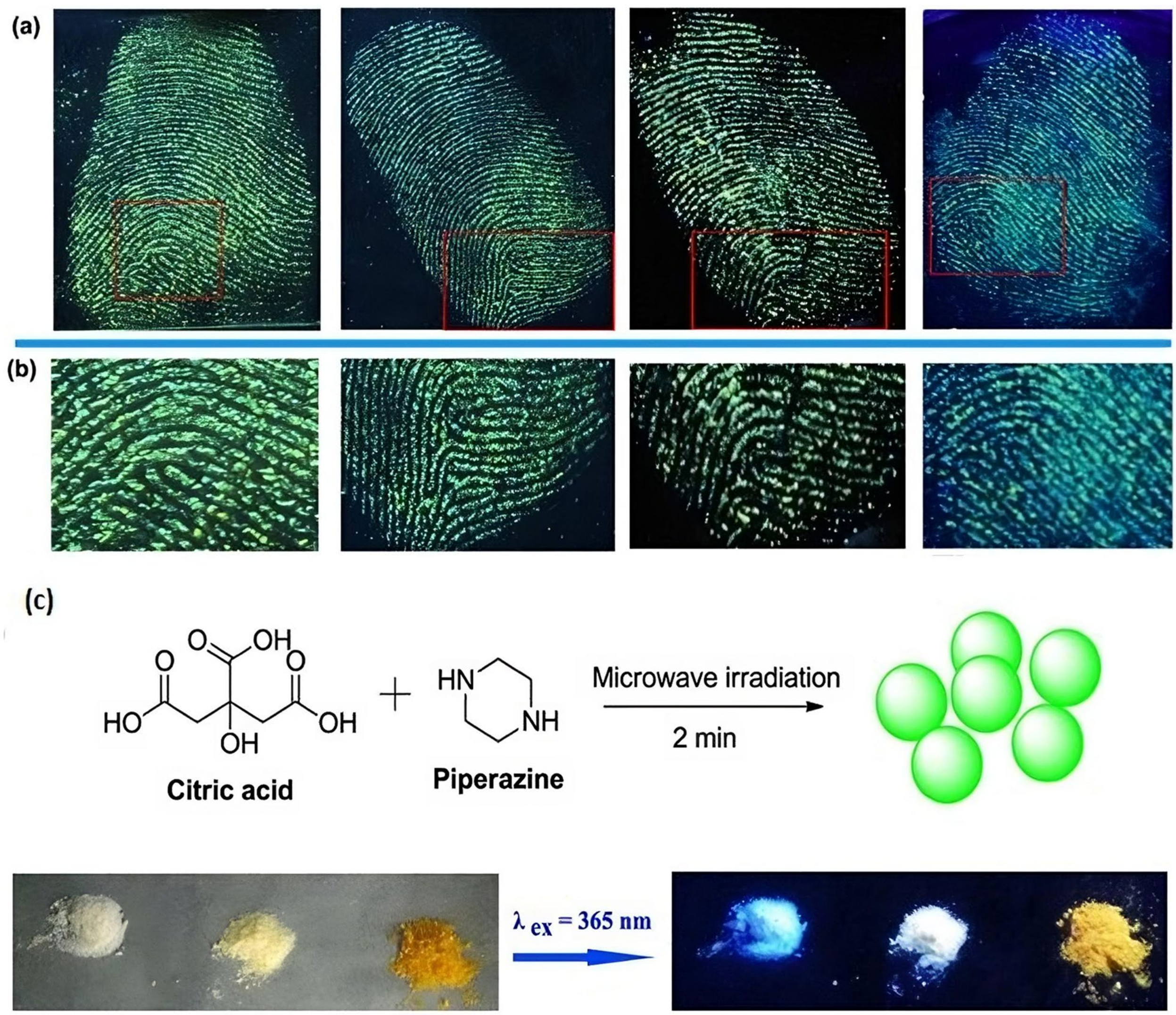

Fig. 5 **a** Photographs of CD's stained fingermarks on different substrate (glass, plastics, tinfoil, and weighing paper) under UV light. **b** The corresponding magnified pictures of above CD's stained fingermarks. **c** Schematic illustration for the synthesis CD's and photographs of the CD's under daylight and UV light (Wang et al. 2018a, b, c) (Dyes and Pigment, 2018, 245-251, with permission from Elsevier)

Feng et al. (2019) used green-emissive CD's (CD-22) to develop fingermarks on litmus paper, glass, orange plastic ruler, and resin tabletop. Green-emissive CD's were diluted with an aqueous solution of starch before its application. Pacquiao et al. (2018) synthesized CD's (CD-23) from enokitake mushroom via hydrothermal method and used these fluorescent CD's to develop fresh and aged (48 h old) latent fingermarks on different surfaces. The developed fingermarks show bright and photostable fluorescence. These fluorescent CD-23 were proposed to be used for diverse applications including imaging, anti-counterfeiting labeling, sensing, and fingermark detection. Wang et al. (2018a, b, c) fabricated the fluorescent carbon dots using the pyrolysis treatment. The synthesized CD– were used to developed the latent fingermarks on various surfaces such as glass, aluminum sheet, stainless steel, polypropylene film, and carnelian and observed under the 365-nm wavelength which gives the blue fluorescence.

Xu et al. (2014) fabricated and used silica-based N-doped CD's (CD-25) to develop latent fingermarks on filter paper. The developed CD's are non-toxic and produce yellowish green fluorescence in aqueous and solid states. Wang et al. (2019) developed and used solid-state fluorescent CD's (CD-26) to develop latent fingermarks on glass, tin foil, plastic, weighing paper, coin, desk, and reagent bottle cap. The use of CD-26 was suggested as an excellent fluorescent coloring reagent for the rapid

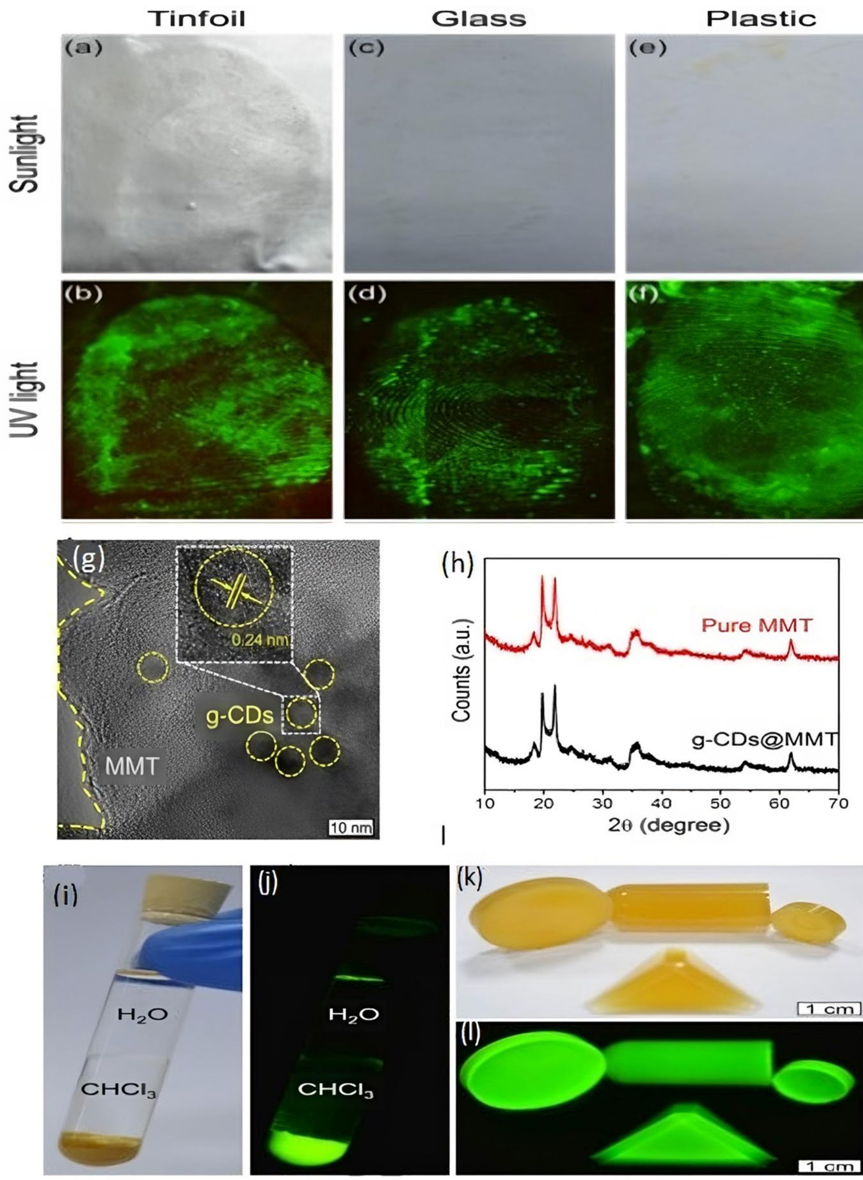

Fig. 6 Latent fingermarks detection images taken under (**a**–**c**) sunlight and (**d**–**f**) UV light using g-CD's@MMT composites as the fluorescent labeling markers on a variety of substances tinfoil (**a** and **d**), glass (**c** and **d**), and plastic (**e** and **f**). **g** HRTEM image. **h** XRD patterns of the g-CD's@MMT composites (black line) and pure MMT (red line). **i** Optical image and (**j**) fluorescent image of the g-CD's@MMT composites in $CHCl_3$. The images of luminescent bulks, which are composed of g-CD's@MMT composites and epoxy silicone resin, are taken under (**k**) sunlight and (**l**) UV light (Thongsai et al. 2017) (Journal of Colloid and Interface Science, 554, 2019, 344–352 with permission from Elsevier)

detection of latent fingermarks on these surfaces. Fluorescent N and S-doped carbon dots@montmorillonite (CD's@PGV) (CD-27) were used to develop latent fingermarks on single and multicolored surfaces including printed metal, glass, plastic, and stainless steel. The developed fingermarks show second-level ridge details due to strong contrast. Due to its high sensitivity, cost-effectiveness, and strong resistance to background interference, the use of these fluorescent N- and S-doped carbon dots@montmorillonite (CD's@PGV) was suggested to develop latent fingermarks on these surfaces (Yu and Yan 2017). Yadav et al. (2018) prepared titanium dioxide co-doped CD's (CD-2) using pomegranate peel extract. The synthesized fluorescent titanium dioxide co-doped CD's were used to develop fresh and aged (7 days old) latent fingermarks on dry and moist aluminum foil, glass, mica sheet, and marble surfaces. The developed fingermarks show excellent fluorescence without any

Table 1 Details of various reported carbon dots (CD) used to develop latent fingerprints

S. no.	Composition	Preparation method	Characterization techniques	Size (nm) and shape	Application method	Surfaces	Luminescence characteristics	Advantages	Reference
	P-doped carbon dots (CD-5)	NR	DLS, FTIR, HRTEM, NMR, PL, RS, X-ray-EDS, XPS, XRD, zeta pot.	220–230, spherical	Powder dusting	Euro banknote, magnetic band, smartphone screen, and metallic surface of credit card	Orange fluorescence at 495 nm	Non-toxic, fast, and cost-effective synthesis	Algarra et al. (2019)
	Cationic carbon dots (CD-17)	Microwave	FTIR, PL, RS, TEM, UV-Vis, XPS, XRD, ZP	2–10	Spraying	Glass, paper, aluminum foil, optical mouse, metallic alloy, porcelain	NR	Biocompatible, tunable fluorescence, safe to use, and 3rd-level details are visible in developed fingerprints	Bahadur et al. (2019)
	CDs–Osi (CD-35)	Solvothermal	UV, PL, HR-TEM, FE-SEM	2.36 nm Spherical	Powder method	Glass, aluminum foil, soft plastic bags, and hard plastic sheets	UV irradiation 365-nm wavelength	NR	Cao et al. (2024)
	Red carbon dots (CD-11)	Hydrothermal	FTIR, PL, TEM, UV-Vis, XPS	2.4	Spraying	Glass, aluminum foil, leather, plastic	Emit bright-red fluorescence under UV light	Fast, user-friendly, and portable, method for fingerprint detection	Chen et al. (2017)
	N-doped carbon dots (CD-10)	Microwave	AFM, FTIR, HRTEM, PL, UV-Vis, XPS, XRD	8.1 (b-CD) 2.69 (o-CD), spherical	NR	Glue film	NR	Ease of use, non-toxicity, good dispersibility	Deng et al. (2019)
	C-dot/p (DMA) (CD-19)	Hydrothermal	DLS, FTIR, NMR, PL, RS, TGA, UV-Vis, XPS	8.7 ± 0.5, spherical	Dipping	Aluminum foil	Fluorescence signal when excited at 350 nm	Non-toxic, luminescent, significant visual contrast	Dilag et al. (2015)
	Blue carbon dots (CD-22)	Hydrothermal	FTIR, PL, TEM, UV-Vis, XPS, XRD	3.2	Powder dusting	Litmus paper, resin tabletop, glass, orange plastic ruler	Blue fluorescence under 365-nm UV light	NR	Feng et al. (2019)
	Silica-based carbon dots (CD-2)	Pyrolysis	FM, PL, TEM	19 ± 2, spherical	Powder dusting	Glass slide, bottle foil	Blue, red, or green when they are excited in the violet, blue, and green wavelength regions	Non-toxic, color tuneability, highly fluorescent hybrid nanopowder	Fernandes et al. (2015)
	CdTe quantum dots (CD-16)	NR	UV, PL, FL, IR	20–50, spherical	Transfer	Glass slide, black ceramic tile, painted polymer material, transparent plastic sheet	Emit fluorescence under 360-nm UV light	Finger ridge Details without background staining, resulting in good contrast For enhanced detection	Gao et al. (2011)

Table 1 (continued)

S. no.	Composition	Preparation method	Characterization techniques	Size (nm) and shape	Application method	Surfaces	Luminescence characteristics	Advantages	Reference
	White carbon dots (CD-9)	Carbonization	HR-TEM, FTIR, NMR, PL, RS, UV-Vis, XPS, XRD	4, spherical	Dipping	Glass	Emit bright white fluorescence under 365-nm UV light	Suppress the ACQ effect	Jiang et al. (2018)
	CdS/PAMAM carbon dots (CD-24)	Pyrolysis	FTIR, PL, TEM, UV-Vis, XRD	10–40, spherical	Powder dusting	Glass, aluminum and copper foils, white ceramic, black marble, coin, iron and zinc sheets, plastic card, adhesive tape	Blue fluorescence under 365-nm UV light	Tunable photoluminescent performance	Jin et al. (2008)
	Zn/N-CDs@hydrotalcite (CD-32)	Hydrothermal method	XRD, SEM, TEM, FTIR, RS XPS, FS	NR	Powder dusting	Clear glass slide, aluminum foil, tiles, plastic Packing of beer bottle, paper, and leather	Fluorescence under 365-nm UV	NR	Li et al. (2023)
	Silica-based carbon dots (CD-8)	Hydrothermal	DLS, FTIR, PL, TEM, XPS, XRD	102.4, monodisperse quasi spherical	Powder dusting	Aluminum foil, marble, transparent tape, wood, ceramic tile, black plastic, stainless steel	Blue fluorescence under 365-nm UV light	Tunable photoluminescence Developed 3-month old fingerprints	Li et al. (2017)
	Carbon dots (CD-7)	Hydrothermal	FESEM, FTIR, PL, TEM, XPS, XRD, zeta pot.	2, spherical quadrilateral	Powder dusting	Glass, plastic	Emit blue fluorescence under 365-nm UV light	An eco-friendly and cost-effective synthesis	Li et al. (2018)
	Starch-based carbon dots (CD-1)	Pyrolysis	UV-Vis, XRD, FT-IR, TEM, fluorescence spectra	10–40 nm, spherical	Powder dusting	Glass slide, aluminum foil, coin, copper foil, zinc sheet, iron sheet, stain less ruler	Blue fluorescence	Well defined Characteristics for finger ridge	Li et al. (2016)
	Orange carbon dots (CD-15)	Hydrothermal	AFM, CLSM, DLS, FTIR, HRTEM, PL, RS, TEM, UV-Vis, XPS	15.9 ± 0.6, quasi-spherical	Spraying	Glass	Emit orange fluorescence with 550-nm excitation	Effective, fast, and user-friendly method for fingerprint detection	Li et al. (2019)
	N-doped carbon dots (CD-12)	Hydrothermal	NMR, PL, TEM, UV-Vis, XPS	6.5, Spherical	Powder dusting	Plastic bag, steel tweezer	Bright fluorescence signal when excited at 350 nm	Non-toxic, bright fluorescence	Milenkovic et al. (2019)
	Luminol-doped carbon dots (CD-33)	Hydrothermal method	EDX-SEM, HR-TEM, FTIR, XPS, UV-visible	12.9 nm	Powder dusting	Glass, coin, costar, plastic	Fluorescence under 395-nm UV	NR	Nugroho et al. (2022)

Table 1 (continued)

S. no.	Composition	Preparation method	Characterization techniques	Size (nm) and shape	Application method	Surfaces	Luminescence characteristics	Advantages	Reference
	Carbon dots (CD-23)	Hydrothermal	FTIR, PL, TEM, UV-Vis, XPS, zeta pot.	4, spherical	Transfer	Glass	Emit blue fluorescence under 360-nm UV light	Non-toxic, easy-to-use, water-soluble carbon dots	Pacquiao et al. (2018)
	ZnO-doped N-carbon dots (CD-3)	Hydrothermal	EDX, FTIR, PL, RS, SEM, TEM, UV-Vis, XRD, zeta nanosizer	20–50	Powder dusting	Aluminum foil, magazine paper, iron disc, black mat, white marble, compact disc	Emit blue fluorescence under 365-nm UV light	Non-toxic	Prabakaran & Pillay (2020)
	Nitrogen-doped carbon dots (CD-13)	Solvothermal	FTIR, HRTEM, PL, UV-Vis, XPS	3.52, spherical	Powder dusting	Silicon wafer	Bright fluorescence signal when excited at 365 nm	Low toxicity, 3rd-level details are visible in developed fingerprints	Ren et al. (2018)
	d-CDs (CD-28)	Thermal processing	XRD, TEM, EDX, FT-IR, RS, PL, PLE	10 nm	Powder dusting	NR	UV-light irradiation	Non-toxic, highly luminescent in the deep-blue region, cost-worthy	Savaedi et al. (2022)
	Orange carbon dots (CD-6)	Hydrothermal	FTIR, HRTEM, PL, UV-Vis, XPS	2.1 ± 0.57, spherical	Droping	Silicon wafer, tape, coin, optical disc, plastic Food package, cardboard, soft drink Paper packaging, meter glass, beer cans	Orange fluorescence with UV light	Non-toxic, fast development, 2nd-level details are visible	Tang et al. (2019)
	Nitrogen-doped carbon dots (CD-14)	Pyrolysis	DLS, FTIR, PL, TEM, UV-Vis, XPS, zeta pot.	8 or 20, spherical	Droping	Glass slide	Fluorescence under UV light	Non-toxic, easy to use, water-soluble NCD	Thongsai et al. (2017)
	Carbon dots (CD-20)	Electrochemical	FTIR, HRTEM, PL, RS, UV-Vis, XPS, XRD, zeta pot.	2.4 ± 0.4, spherical	Spraying	NR	Emit blue fluorescence at 365 nm	Fast and cost-effective method, low toxicity, photostable, water-dispersible carbon dots	Wang et al. (2014)
	Nitrogen- and sulfur-doped solid fluorescent carbon dots (CD-39)	Microwave	AFM, FTIR, NMR, PL, TEM, UV-Vis, XPS, zeta pot.	2–7	Powder dusting, spraying	Aluminum, foil, glass, plastic, steel, paper, ceramic	NR	Stable, strong color-tunable fluorescence, 3rd-level details are visible in developed fingerprints	Wang et al. (2018a, b, c)

Table 1 (continued)

S. no.	Composition	Preparation method	Characterization techniques	Size (nm) and shape	Application method	Surfaces	Luminescence characteristics	Advantages	Reference
	Carbon dots (CD-18)	Microwave or pyrolysis	FTIR, HRTEM, PL, TEM, UV-Vis, XPS XRD	3.2–7.8, spherical	Powder dusting	Glass, plastic, tin foil, weighing paper	Emit green-yellow fluorescence under 365-nm UV light	Self-quenching-resistant, tunable, solid-state fluorescence	Wang et al. (2018a, b, c)
	Carbon dots (CD-38)	Pyrolysis	FM, FTIR, HRTEM, PL, RS, SEM, UV-Vis, XPS, XRD	3.36, spherical	Dropping	Glass, aluminum sheet, stainless steel, polypropylene film, carnelian	Emit blue fluorescence under 365-nm UV light	Non-toxic, photostable, tunable fluorescence	Wang et al. (2018a, b, c)
	P-carbon dots (CD-26)	Hydrothermal	FTIR, HRTEM, PL, SEM, UV-Vis, XRD, Zeta Pot.	6, spherical	Powder dusting	Desk, reagent bottle cap, and coin	Emit violet-blue fluorescence under 365-nm UV light	Non-toxic, chemically stable	Wang et al. (2019)
	Grain-doped carbon dots (CD-31)	Hydrothermal	XRD, XPS, TEM, UV, PL	2–25 nm, spherical	Powder dusting	Glass slide, aluminum foil, cigarette packs, mouse	365-nm UV light developed by R-dots	High sensitivity and wider applicability, simple, low-cost, low toxicity	Wang et al. (2020)
	SSF-emitting CD (CD-29)	Microwave	PL, FT-IR, XPS	NR	Powder dusting	Paper currency, coin, steel ruler, tinfoil	Blue fluorescence under 395 nm	NR	Wang et al. (2021)
	S-R-CD S-O-CD S-Y-CD (CD-30)	Solvothermal method	XPS, TEM, HRTEM, XRD, UV-Vis	7.8, 6.0, and 3.5 nm Spherical	Powder dusting	Glass slide, ceramic tile, painted wood, aluminum alloy plate, banknote	NR	NR	Wang et al. (2022)
	R-CDs Y-CDs G-CDs (CD-34)	NR	TEM, HR-TEM, XRD, PL, FL, Raman spectra, XPS, FT-IR, UV-Vis	4.35 nm, 4.12 nm, and 3.51 nm, respectively	NR	Glass slide	Red, yellow, and green	High contrast of fluorescent signals	Xu et al. (2023)
	Carbon dots (CD-25)	Microwave	FTIR, HRTEM, PL, TEM, UV-Vis, XPS, XRD	1.5 ± 0.3, spherical	Powder dusting	Glass, tin foil, plastic, weighing paper, coin, reagent bottle cap, desk	Emit bright yellow-green solid-state fluorescence under 365-nm UV light	Rapid synthesis, tunable fluorescence, no background fluorescence interferences	Xu et al. (2014)
	Titanium dioxide-doped carbon dots (CD-36)	Hydrothermal	EDX, FTIR, HRTEM, PL, RS, SEM, TEM, UV-Vis, XRD	2–5, spherical	Powder dusting	Glass, aluminum foil, marble, mica sheet	NR	Non-toxic, thermally stable, 3rd-level details are visible	Yadav et al. (2018)

Table 1 (continued)

S. no.	Composition	Preparation method	Characterization techniques	Size (nm) and shape	Application method	Surfaces	Luminescence characteristics	Advantages	Reference
	Cdots@PGV (CD-27)	Microwave	UV, PL, XRD, FT-IR, SEM, HR-TEM	6 nm, spherical	Powder dusting	Glass slides, painted metal, plastic products, stainless steel	Violet-blue fluorescence under UV irradiation (365 nm)	Low toxicity, recommended to work in a well-ventilated room, or upwind	Yu and Yan (2017)
	Green carbon dots (CD-21)	Microwave	EDX, FTIR, HRTEM, PL, SEM, UV-Vis, XPS, XRD, ZP	NR	Powder dusting	Glass, tin foil, plastic	Emit green fluorescence under UV light	Low toxicity, excellent thermal and photo stability	Zhai et al. (2019)
	Silica-based carbon dots (CD-37)	Pyrolysis	DLS, FTIR, PL, TEM, UV-Vis	141, spherical; DLS = 1.8-nm centered at particle size	Powder dusting	Aluminum foil, glass, plastic bags, leather, drug packings	415-nm excitation with yellow filter	Non-toxic, tunable fluorescence, high sensitivity, reduce background interference	Zhao et al. (2017)
	Green-emitting carbon dots (CD-4)	Hydrothermal	FTIR, PL, UV-Vis, XPS	NR	Immersion	Glass, tin foil, transparent tape, sealing bag	Emit green fluorescence under 365-nm UV light	NR	Zhao et al. (2018)

NR not reported, *AFM* atomic force microscopy, *DLS* dynamic light scattering, *EDX* energy-dispersive X-ray spectroscopy, *EDX-SEM* energy-dispersive X-ray spectroscopy-scanning electron microscopy, *FESEM* field emission scanning electron microscopy, *FETEM* field emission transmission electron microscopy, *FM* fluorescence microscopy, *FS* fluorescence spectroscopy, *FTIR* Fourier transform-infrared spectroscopy, *HRTEM* high-resolution transmission electron microscopy, *NMR* nuclear magnetic resonance, *PL* photoluminescence spectroscopy, *PLE* photoluminescence excitation, *RS* Raman spectroscopy, *SEM* scanning electron microscopy, *TEM* transmission electron microscopy, *TGA* thermogravimetric analysis, *UV-Vis* UV-visible spectroscopy, *XEDS* X-ray energy dispersion spectroscopy, *XPS* X-ray photoelectron spectroscopy, *XRD* X-ray diffraction spectroscopy background interference. The developed fingermarks were clear and identifiable in nature showing third-level ridge details. Wang et al. (2018a, b, c) successfully synthesized the nitrogen- and sulfur-doped solid fluorescent carbon dots (N, S-SFCD) (CD-39) with a simple microwave-assisted method. The synthesized CD-39 was used to develop latent fingermarks on various surfaces like aluminum foil, steel, glass, plastics, ceramic, and printing paper. The developed fingermarks were very good in quality that 2nd and 3rd level of identification can be easily done using this powder.

Savaedi et al. (2022) developed the deep blue-emissive doped-CD's (d-CD's) (CD-28) with high photoluminescence up to 62%. The synthesized nanoparticles were used to develop the latent fingermarks due to its highly luminescence in deep-blue region property and cost-effectiveness. Wang et al. (2021) synthesized the SSF-emitted CD's (CD-29) for the development of latent fingermarks using the simple microwave-assisted method. The synthesized powder was used on various surfaces such as paper currency, coin, steel ruler, and tinfoil on fresh and 6-month aged fingermarks and observed under the 365-nm UV light. Similarly, three different types of CD's (S-R-CD's, S-O-CD's, S-Y-CD's) (CD-30) were synthesized using solvothermal route. These powders were used to develop the latent fingermarks on glass slide, aluminum alloy plate, ceramic tile, painted wood, and banknote upon the 365-nm irradiation in a dark field. Furthermore, the second-level identification of fingermarks was clearly observed (Wang et al. 2022). Wang et al. (2020) synthesized the series of the carbon nanodots (CD-31) using the grain (wheat, corn, sorghum, rice) have been prepared by hydrothermal method. Further development of latent fingermarks was done on the glass slide, aluminum foil, cigarette packs, and mouse. This method provides the cost-effective, simple synthesize route, and promising powder to develop latent fingermarks.

Li et al. (2023) reported the synthesis of Zn-assisted N-doped CD's (Zn/N-CD's@hydrotalcite) (CD-32) for enhancing the fluorescence and used in the application of fingermark. The synthesized powder reacted to the universal fingermark residue through electrostatic interaction and physical adsorption. Using this powder, the latent fingermarks were developed on the glass, aluminum foil, tiles, plastic packing of beer bottle, paper, and leather. Thus, the result shows that the 2nd- and 3rd-level identification can be done for individual identification. Nugroho et al. (2022) prepared the CD's (CD-33) by adding luminol to coconut water and ethanol using hydrothermal method. This synthesized powder developed the latent fingermarks on nonporous surfaces (glass, plastic); also, they measure the effect of temperature and storage time of the materials which shows that the prepared powder can developed the latent fingermark after the 30 days storage of powder. Xu et al. (2023) reported the solid-state multicolor fluorescent carbon dots for the detection of latent fingermarks. In this study, three different R-CDs, Y-CDs, and G-CDs (CD-34) were used to developed the latent fingermark on the glass and observed under UV irradiation. Under the UV irradiation, second-level characteristics such as island, bifurcations, terminations, eyes, nuclei, and ridge divergence were clearly observed. Cao et al. (2024) synthesized CDs embedded in organosilicon (CDs–OSi) composites (CD-35) using the solvothermal method. The synthesized powder was used to developed latent fingermarks on

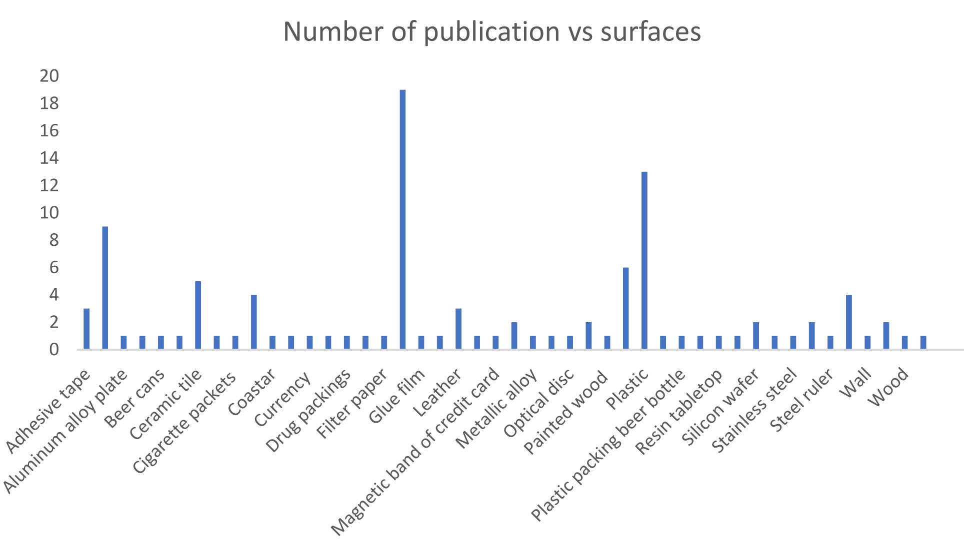

Fig. 7 Various surfaces in reported work

Table 2 Type of surfaces on which carbon dots (CD) were used to develop latent fingerprints

S. no.	Surfaces	Composition	References
1.	Adhesive tape	Silica-based carbon dots; starch-based carbon dots; orange carbon dots	Li et al. (2017); Li et al. (2016); Tang et al. (2019)
2.	Aluminum foil	Silica-based carbon dots; C-dot/p (DMA); red carbon dots; nitrogen- and sulfur-doped solid fluorescent carbon dots; starch-based carbon dots; cationic carbon dots	Zhao et al. (2017); Li et al. (2017); Dilag et al. (2015); Chen et al. (2017); Wang et al. (2018a, b, c); Li et al. (2016); Bahadur et al. (2019); Li et al. (2023); Wang et al. (2020); Cao et al. (2024)
3.	Aluminum alloy plate	Multicolor carbon dots	Wang et al. (2022)
4.	Bank note	Multicolor carbon dots	Wang et al. (2022)
5.	Beer cans	Orange carbon dots	Tang et al. (2019)
6.	Cardboard	Orange carbon dots	Tang et al. (2019)
7.	Ceramic tile	Silica-based carbon dots; starch-based carbon dots; nitrogen- and sulfur-doped solid fluorescent carbon dots	Li et al. (2017); Li et al. (2016); Wang et al. (2018a, b, c); Wang et al. (2022); Li et al. (2023)
8.	Cloth	N-doped carbon dots	Liu et al. (2019a, b)
9.	Cigarette packets	Solid-state photoluminescent Carbon nanodots	Wang et al. (2020)
10.	Coin	Starch-based carbon dots; orange carbon dots; carbon dots	Li et al. (2016); Tang et al. (2019); Wang et al. (2019); Nugroho et al. (2022)
11.	Coastar	Luminol carbon dots	Nugroho et al. (2022)
12.	Copper foil	Starch-based carbon dots	Li et al. (2016)
13.	Currency	SSF-emitting carbon dots	Wang et al. (2021)
14.	Desk	Carbon dots	Wang et al. (2019)
15.	Drug packings	Silica-based carbon dots	Zhao et al. (2017)
16.	Euro banknote	P-doped carbon dots	Algarra et al. (2019)
17.	Filter paper	N-doped carbon dots	Xu et al. (2014)
18.	Glass	Silica-based carbon dots; starch-based carbon dots; white carbon dots; orange carbon dots; orange carbon dots; carbon dots; nitrogen-doped carbon dots; green carbon dots; carbon dots; red carbon dots; nitrogen- and sulfur-doped solid fluorescent carbon dots; carbon dots; N-doped carbon dots; blue carbon dots; cationic carbon dots	Fernandes et al. (2015); Zhao et al. (2017); Li et al. (2016); Jiang et al. (2018); Li et al. (2019); Tang et al. (2019); Li et al. (2018); Thongsai et al. (2017); Zhai et al. (2019); Wang et al. (2018a, b, c); Chen et al. (2017); Wang et al. (2019); Liu et al. (2019a, b); Feng et al. (2019); Bahadur et al. (2019); Wang et al. (2022); Nugroho et al. (2022); Li et al. (2023); Xu et al. (2023); Cao et al. (2024) filter
19.	Glue film	N-doped carbon dots	Deng et al. (2019)
20.	Iron sheets	Starch-based carbon dots	Li et al (2016)
21.	Leather	Silica-based carbon dots; red carbon dots	Zhao et al. (2017); Chen et al. (2017); Li et al. (2023)
22.	Litmus paper	Blue carbon dots	Feng et al. (2019)
23.	Magnetic band of credit card	P-doped carbon dots	Algarra et al. (2019)
24.	Marble	Starch-based carbon dots; silica-based carbon dots	Li et al. (2016); Li et al. (2017)
25.	Metallic alloy	Cationic carbon dots	Bahadur et al. (2019)
26.	Metallic surface of credit card	P-doped carbon dots	Algarra et al. (2019)
27.	Optical disc	Orange carbon dots	Tang et al. (2019)
28.	Optical mouse	Cationic carbon dots	Bahadur et al. (2019); Wang et al. (2020)
29.	Painted wood	Multicolor carbon dots	Wang et al. (2022)

Table 2 (continued)

S. no.	Surfaces	Composition	References
30.	Paper	N-doped carbon dots; orange carbon dots; cationic carbon dots; nitrogen- and sulfur-doped solid fluorescent carbon dots	Liu et al. (2019a, b); Tang et al. (2019); Bahadur et al. (2019); Wang et al. (2018a, b, c); Wang et al. (2021); Li et al. (2023)
31.	Plastic	Silica-based carbon dots; carbon dots; green carbon dots; carbon dots; red carbon dots; nitrogen- and sulfur-doped solid fluorescent carbon dots; carbon dots; silica-based carbon dots; starch-based carbon dots; N-doped carbon dots; orange carbon dots; blue carbon dots	Zhao et al. (2017); Li et al. (2018); Zhai et al. (2019); Wang et al. (2018a, b, c); Chen et al. (2017); Wang et al. (2018a, b, c); Wang et al. (2019); Li et al. (2017); Li et al. (2016); Milenkovic et al. (2019); Tang et al. (2019); Feng et al. (2019); Nugroho et al. (2022)
32.	Porcelain	Cationic carbon dots	Bahadur et al. (2019)
33.	Plastic packing beer bottle	Solid-state fluorescence carbon dots	Li et al. 2023)
34.	Reagent bottle cap	Carbon dots	Wang et al. (2019)
35.	Resin tabletop	Blue carbon dots	Feng et al. (2019)
36.	Rigid plastic sheet	Carbon dots embedded in organosilicon	Cao et al. (2024)
37.	Rubber	N-doped carbon dots	Liu et al. (2019a, b)
38.	Silicon wafer	Nitrogen-doped carbon dots; orange carbon dots	Ren et al. (2018); Tang et al. (2019)
39.	Smartphone screen	P-doped carbon dots	Algarra et al. (2019)
40.	Soft plastic bag	Carbon dots embedded in organosilicon	Cao et al. (2024)
41.	Stainless steel	Silica-based carbon dots	Li et al. (2017)
42.	Steel tweezer	N-doped carbon dots; nitrogen- and sulfur-doped solid fluorescent carbon dots	Milenkovic et al. (2019); Wang et al. (2018a, b, c)
43.	Steel ruler	SSF-emitting carbon dots	Wang et al. (2021)
44.	Tin foil	Green carbon dots; carbon dots; carbon dots	Zhai et al. (2019); Wang et al. (2018a, b, c); Wang et al. (2019); Wang et al. (2021)
45.	Wall	N-doped carbon dots	Liu et al. (2019a, b)
46.	Weighing paper	Carbon dots; carbon dots	Wang et al. (2018a, b, c); Wang et al. (2019)
47.	Wood	Silica-based carbon dots	Li et al. (2017)
48.	Zinc sheets	Starch-based carbon dots	Li et al. (2016)

glass, aluminum foil, soft plastic bags, and hard plastic sheets and observed under the 365-nm UV irradiation. Using this powder, the third level of identification features was clearly observed.

It is observed that starch and orange-emitting ones are most the versatile CD's to develop latent fingermarks on wide range of surfaces. It is observed that glass and plastic are most frequently used surfaces to demonstrate the utility of newly synthesized CD's as a fingermark reagent. It may be due to their easy availability, cost-effectiveness, and inertness. In addition to this, simple and fast development showing fine ridge details on these surfaces makes them the first choice of researchers to use them for demonstration purposes.

CD's can be used in powder or solution form to develop latent fingermarks. In powder form, CD's are applied by powder dusting technique, while in solution form, it can be applied by spraying, dipping, or dropping method. CD's are used as a luminescent agent in powder form. The use of CD's in solution form is more suitable as in this form its surface functionalization and luminescence properties can be fully exploited. However, in contrast to this, the use of CD's in powder form is more commonly reported than in solution form as observed in the present review (Table 1). This may be attributed to the simple and fast application procedure in powder form, and unlike the solution form, there is no need of costly and toxic solvents. This makes powder dusting a convenient, cost-effective, and simple method to apply CD's to latent fingermarks bearing surfaces as shown in Fig. 7.

Although it is observed that some studies try to follow the standardization protocol for latent fingermark reagent, but not even a single study compares the results of CD's processing with benchmark techniques. In addition to this, mechanism of interaction between CD's and residues of latent fingermarks should be explored to improve the selectivity and quality of developed fingermarks. The use of CD's for detecting latent fingermarks has not been fully explored to date, and more studies need to be performed in order to address these issues.

In that scenario, the forensic examiners can be released from the need to carry and use a number of different powders to accommodate a variety of backgrounds at the crime scene as shown in Table 2. CD's can be readily used in the crime scene, following standard forensic procedures.

Conclusions

In recent years, nanoparticles gained a lot of interest for the development of latent fingermarks. This is because they show lot of favorable characteristics such as small size, high contrast, facile and low-cost synthesis, and color tuneability that helps to overcome the limitations of the conventional reagents, namely low sensitivity, low selectivity, high background interference, poor contrast, and low resolution. In this present study, we review the use of CD's in latent fingermark analysis. CD's represent a rapidly growing class of nano-emitters that may help the creation of new and effective fingermark development method for law enforcement and criminal justice. The advantage of using these CD's primarily lies in their relative non-toxicity as compared to inorganic quantum dots and cheaper production costs. CD's were used as reagents for the fingermark development on several surfaces such as printing paper, aluminum foil, copper, glass, rubber, leather, tin foil, plastic, weighing paper, currency coins, reagent bottle cap, and furniture. On review of the reports, it is observed that CD's have a huge potential to be used to develop latent fingermarks worldwide by the crime scene investigators, fingermark experts, and police personnels as an affordable reagent with a quick response time on a variety of surfaces.

Abbreviations

AFIS	Automated Fingerprint Identification System
CD's	Carbon dots
DFO	1,8-Diazafluoren-9-one
IND	1,2-Indanedione
NIN	Ninhydrin
NIR	Near-infrared
ORO	Oil red O
PD	Physical developer
QD	Quantum dot
SPR	Small particle reagent
UV	Ultraviolet

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Authors' contributions
AG, literature survey, compilation of data in table, and overall compilation of draft. LD, literature survey, editing, and assisting in manuscript writing. JM, writing and assisting in compilation of data. GB, literature survey, conceptualizing the manuscript, overall supervision, writing, editing, and finalizing the manuscript. AD, conceptualizing the manuscript, overall supervision, review, editing, and finalizing the manuscript.

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Availability of data and materials
Since this is a review, no new experimental data was included apart from what is already available in the literature.

Declarations

Ethics approval and consent to participate
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Consent for publication
On behalf of all the authors, the corresponding author states that all authors have provided consent for publication.

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