GREEN SYNTHESIS OF NANOPARTICLES AND ITS APPLICATION ON LATENT FINGERPRINTS IMAGING

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By

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Approval Sheet

This thesis entitled "**GREEN SYNTHESIS OF NANOPARTICLES AND ITS APPLICATION ON LATENT FINGERPRINTS IMAGING"** by **Ms. KAJOL BHATI** is approved for the degree of **Ph.D. Forensic Science**.

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis, entitled "**GREEN SYNTHESIS OF NANOPARTICLES AND ITS APPLICATION ON LATENT FINGERPRINTS IMAGING** " in fulfillment of the requirements for the award of the degree of **Doctor of Philosophy in Forensic Science** and submitted in **Galgotias University**, Greater Noida is an authentic record of my own work carried out during a period from 2019-2023 under the supervision of **Dr. Divya Tripathy**, Professor, Department of Chemistry, School of Basic Sciences, Galgotias University, Greater Noida, India and **Dr. Shruti Shukla**, Senior Scientist, TERI-Deakin Nanobiotechnology Centre, Sustainable Agriculture The Energy and Resource Institute (TERI), New Delhi, India.

The matter embodied in this thesis has not been submitted by me for the award of any other degree of this or any other University/Institute.

(Kajol Bhati)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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The Ph.D. Viva-Voice examination of_____Research Scholar, has been held on_____.

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ABSTRACT

ABSTRACT OF THESIS

A fingerprint is an impression left by the friction ridge of a finger. The friction ridges are present on overall surface of the fingers that leads to the finger-impressions. The impressions are present on the fingers, also present on the toes and soles of the feet as well as on the hands and palms. The fingerprint patterns are distinctive, till date, it has not been observed that any two people, including identical monozygotic twins, have the same fingerprints. The fingerprints are unaffected by superficial wounds, and the same pattern or design persists even after new skin has grown. When we touch any surface or objects, we leave imprints on it. These may or may not be visible prints. The invisible finger impressions are developed using various powder dusting and chemical methods like Iodine fuming, ninhydrin, cyanoacrylate, silver nitrate method. The traditional powder-dusting method has some disadvantages in terms of low sensitivity, less contrast, toxic in nature, and high autofluorescence intrusion. Therefore, to overcome these disadvantages and to get more accurate and precise results the use of nanoparticles has come into practice as a better choice. The present study focuses on the synthesis of nanoparticles using ecofriendly resources. From the two compounds, Silica and Graphene nanoparticles has been synthesized. The Mesoporous Silica nanoparticles (MSNPs) was synthesized by sol-gel method whereas, Graphene Nanosheets (GNS) was synthesized by pyrolysis technique. For the synthesis of MSNPs, 0.055 M n-hexadecyl-trimethylammonium bromide (CTAB) aqueous solution was prepared in 10 mL MilliQ water under vigorous stirring for 30 min followed by heating at 60°C for 15 min and cooled to room temperature and further added to a solvent mixture containing 5 mL of methanol, 95 mL of MilliQ water, 3 mL of ammonium hydroxide (NH_4OH), 20 mL of ethyl acetate ($CH_3COOC_2H_5$) under stirring condition and then 300 μL of tetraethyl orthosilicate (TEOS) was added to the reaction solution. The resulting solution was stirred for 12 hours. The synthesized MSNPs were washed with excess ethanol and stored in 40 mL ethanol until further use. The CTAB was extracted by adjusting the pH to 1.6 and stirring for 3 hours at 60 °C and washed using ethanol. The pellet was dispersed in 20 mL of ethanol and stored at room temperature. The Graphene nanosheets were synthesized using chickpeas as a precursor by pyrolysis method. The 2 g of powdered chickpea sample was put in a capped quartz boat and heated at 800°C for 2 hours at a heating rate of 5°/ min under an inert environment. Such synthesized soot was collected and treated with nitric acid to introduce hydrophilic groups. Typically, 1 g of soot was taken in 100 mL nitric acid (60%) and reflux for 12 hours. The supernatant was collected *via* centrifugation and evaporated at a

water bath until a slurry was formed. Afterward, 500 mL water was added to it and evaporated, this process was repeated to remove excess acid. When pH reached 7.0, the slurry was dried at room temperature and GNS were collected (yield 60%). The characterization of both the nanoparticles for various factors were done by FTIR, XRD, SEM, TEM, HR-TEM, Raman spectroscopy, EDS, UV-Vis spectrophotometer and Fluorescence microscopy. The synthesized nanoparticles were used for the development of latent finger-impressions on various porous and non-porous surfaces like glass, paper, wooden surface, steel cup, and plastic lid. MSNPs and GNS developed latent fingerprints on non-porous surfaces with clear appearance of class and individual characteristics, whereas fingerprints are not developed on porous surfaces.

DEDICATED

To My Parents and Life

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Kajol Bhati

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1	**Waste biomass originated biocompatible fluorescent graphene nano-sheets for latent fingerprints detection in versatile surfaces**	Catalysts	SCI, SCOPUS	2023
2	**Sensitive Fingerprint Detection Using Biocompatible Mesoporous Silica Nanoparticle Coating on Non-porous Surfaces**	Coatings	SCI, SCOPUS	2023
3	**Role of Fluorescence Substances in Development of Latent Fingerprints: A Review**	Indian Journal of Forensic Medicine and Pathology	SCOPUS	2021
4	**Role of Nanotechnological Techniques in Fingerprints Enhancement: A Review**	Indian Journal of Forensic Medicine and Pathology	SCOPUS	2021
5	**Role of nanoparticles in fingerprints: An Update.**	Letters in Applied BioNanosciences	SCOPUS	2020

LIST OF ABBREVIATIONS

MMD	Multi Metal Deposition
VMD	Vacuum Metal Deposition
SPR	Small Particle Reagent
nm	Nanometers
PEG	Polyethylene glycol
MRI	Magnetic Resonance Imaging
FTIR	Fourier Transform Infrared Spectroscopy
SEM	Scanning Electron Microscopy
TEM	Transmission Electron Microscopy
DLS	Dynamic Light Scattering
XRD	X-ray Diffraction
AFM	Atomic Force Microscopy
SiO_2	Silicon Oxide
NPs	Nanoparticles
TX	Triton X
NaCl	Sodium chloride
RPM	Resolution per minute
MSNs	Monodisperse Silica Nanoparticles/ Mesoporous Silica Nanoparticles
NCDs	N-doped carbon dots
pg-C_3N_4	Porous graphitic carbon nitride
SlG	Silica Gel
TMMS	Trimethoxymethylsilane
MNPs	Magnetic nano powders

EDX	Energy-dispersive X-ray
LFP	Latent fingerprints
GCDs	Graphene Carbon Dots
IPA	Isopropyl alcohol
DI	De-ionized
CNPs	Carbon nanoparticles
AuNPs	Gold nanoparticles
NCO	Nanocomposite
FE-SEM	Field Emission Scanning Electron Microscope
TEA	Triethylamine
CTAC	Cetyltrimethylammonium citrate
MB	Methylene blue
GNS	Graphene Nano-Sheets
CTAB	Cetyltrimethylammonium bromide
HCl	Hydrochloric acid
BJH	Barrett–Joyner–Halenda
BET	Brunauer–Emmett–Teller
UV-Vis	Ultraviolet-Visible
PL	Photoluminescence
BEAS	Bronchial Epithelium Cells
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenylshytetrazolium bromide
DMSO	Dimethyl sulfoxide
LB	Luria-Bertani
PBS	Phosphate-buffered saline

MIC	Minimum Inhibitory Concentration
AO	Acridine orange
EB	Ethidium bromide
XPS	X-ray Photoelectron Spectroscopy
B. cereus	Bacillus cereus
QDs	Quantum Dots

CHAPTER-1

INTRODUCTION

1. INTRODUCTION

A fingerprint is an impression left by the friction ridge of a finger. The friction ridges are present on overall surface of the fingers that leads to the finger-impressions. The impressions are present on the fingers are also present on the toes and soles of the feet as well as on the hands and palms (Champod *et al*., 2017). The study of the skin patterning on fingers, palms, soles and toes is termed as Dermatoglyphics and the study of ridge patterns on finger ball is called as fingerprints. The purpose of these friction ridges is grasping or holding on to the surface. The friction ridges which are made up of various furrows and minor ridges are the main factor in the identification of an individual human. Instead of flowing constantly, the ridges bend and curve, stop and start, come together, and split away, resulting in a distinctive group of characteristics called patterns (M. R. Hawthorne *et al*., 2021). The ridges grow during the foetus development in the womb before birth, and unless there is a serious wound that pierces the epidermal layer of skin, these pattern will not modify until after death (M. Hawthorne, 2017). Their structure is a result of a variety of variables, including the physical factors like tensions and stresses experienced by the skin as it develops in the womb, hormones, and heredity. Numerous sweat pores can be found running along the crest of each ridge. These constantly exude sweat, which, when touches a surface that is receptive, leaves a mark like a ridge pattern.

Fingerprints are unique to an individual and persistent which does not change with age. They cannot be destroyed, even if damaged. The factors considered for identification are so wide that it is almost impossible to abolish all the fingerprint details of a person (Saks & Koehler, 2008). They can be lost only with the loss of limb/phalanges but still since all ten phalanges prints are recorded, in case of a criminal, so impersonation is not possible (Daluz, 2018).

The fingerprints are unique in nature which leads them to be distinctive from the other evidences. There are three principles of fingerprints –

Principle of individuality- A fingerprint is a distinctive feature. No similar ridge characteristics have yet been seen in any two fingers.

Principle of persistency - A fingerprint will not alter during a person's life.

Principle of Variety - Fingerprints can be categorized systematically due to their common ridge patterns (Crispino & Houck, 2013; Houck, 2016).

Fingerprints plays as important role in personal identification that considered as the greatest contribution to law enforcement. The fingerprints have its own science which plays unique role for justice and in further areas where positive identification is important. Fingerprint science can help in criminal identification if it is found as the evidence at the crime scene. It also provides the support to the prosecutors when they present their cases considering the defendant's prior criminal history. The fingerprint data record of criminals can be exchanged for the criminal identification with foreign investigation agencies in situations when there is a common interest providing the assistance for the decision-making of probation or parole officers as well as parole boards (McCartney, 2013).

The fingerprint patterns are distinctive, till date, it has not been observed that any two people, including identical monozygotic twins, have the same fingerprints *(Rahat et al., 2020; Sun et al*., 2010). When we touch any surface or objects, we leave imprints on it. These may or may not be visible prints. The fingerprints are unaffected by superficial wounds, and the same pattern or design persists even after new skin has grown. From the past 100 years, fingerprints have helped governments all over the world to identify criminals with accuracy. They serve as the cornerstone for all police departments throughout the world to record criminal histories. Most forensic cases include the use of fingerprints above other types of evidence. In terms of identifying more criminals, fingerprints have surpassed DNA and all other human identification technologies (Dror & Mnookin, 2010).

1.1. BIOLOGICAL DEVELOPMENT OF FINGER-IMPRESSION

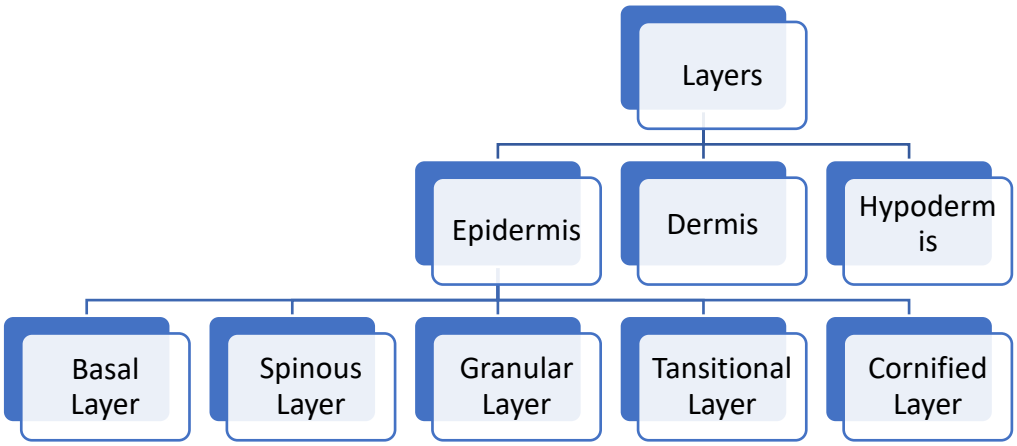


Figure 1.1: Skin layers

Epidermis, dermis, and hypodermis are the three anatomical layers that make up the skin as an organ. Together, these physiological layers serve to give the organism a barrier of protection, control over body temperature, sensibility, excretion, immunity, a blood reservoir, and the ability to produce vitamin D.

The epidermis is the outer layer of the skin which acts as a protection layer for underlying tissues. It helps in the water retention occur by evaporation, and works as a receptor organ. A layer of connective tissue called the dermis supports the epidermis. The epidermis receives structural support and nutrients from this network of cells, fibres, blood vessels, and gelatinous substance. The dermis participates in sensory perception, temperature regulation, and blood storage. Under the dermis, in a loose connective tissue layer is the hypodermis, also known as the subcutaneous tissue which comprises a cushion of adipose cells, that also sculpt the body and act as an energy reserve. The hypodermis helps regulate body temperature by providing insulation and serves as a cushion to protect internal organs and bones. The epidermis and dermis, as well as the hypodermis and dermis, are connected by fibres.

The ridges are formed during foetal development and are unique to everyone, making them useful in forensic identification (Wertheim, 2011). The biological development of friction ridges takes place as follows-

- *Embryonic development*: The formation of friction ridges begins during embryonic development, around the eighth week of gestation. The ridges are thought to be formed by the buckling of the underlying dermal tissue as the fingers and toes grow and lengthen.
- *Prenatal development*: As the foetus grows, the friction ridges continue to develop and become more complex. By the end of the fourth month of gestation, the ridges have formed their characteristic arches, loops, and whorl.
- *Postnatal development*: After birth, the friction ridges continue to develop and mature. The ridges become more pronounced and defined, and the patterns become more complex and unique to everyone (Wertheim, 2011).

The development of friction ridges is thought to be influenced by both genetic and environmental factors, such as foetal movements and pressure within the uterus. While the exact function of friction ridges is not fully understood, they are believed to improve grip and

enhance tactile sensitivity, making them an important feature of the human hands and feet (Maceo, 2011).

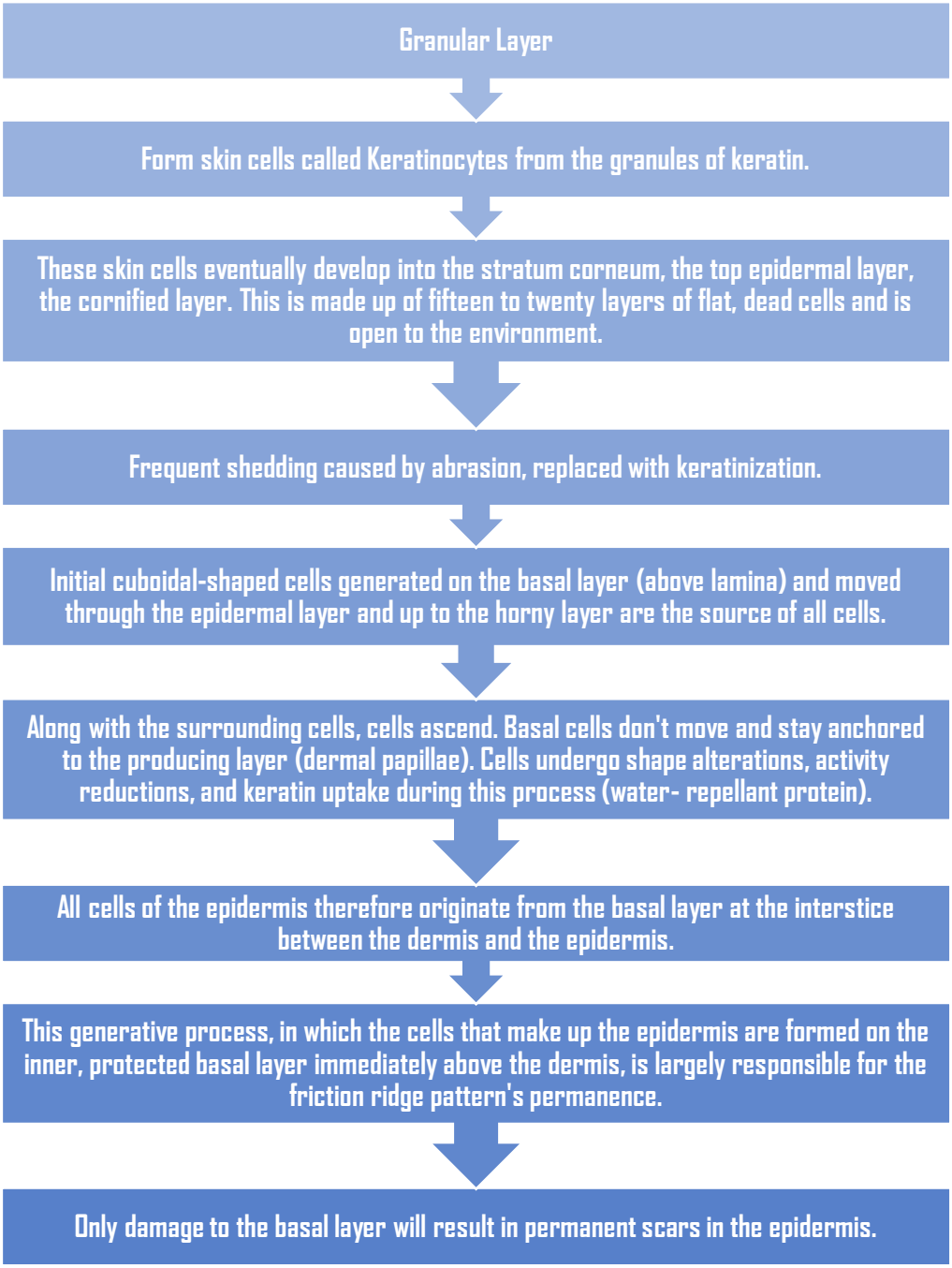


Figure 1.2: Formation of layers

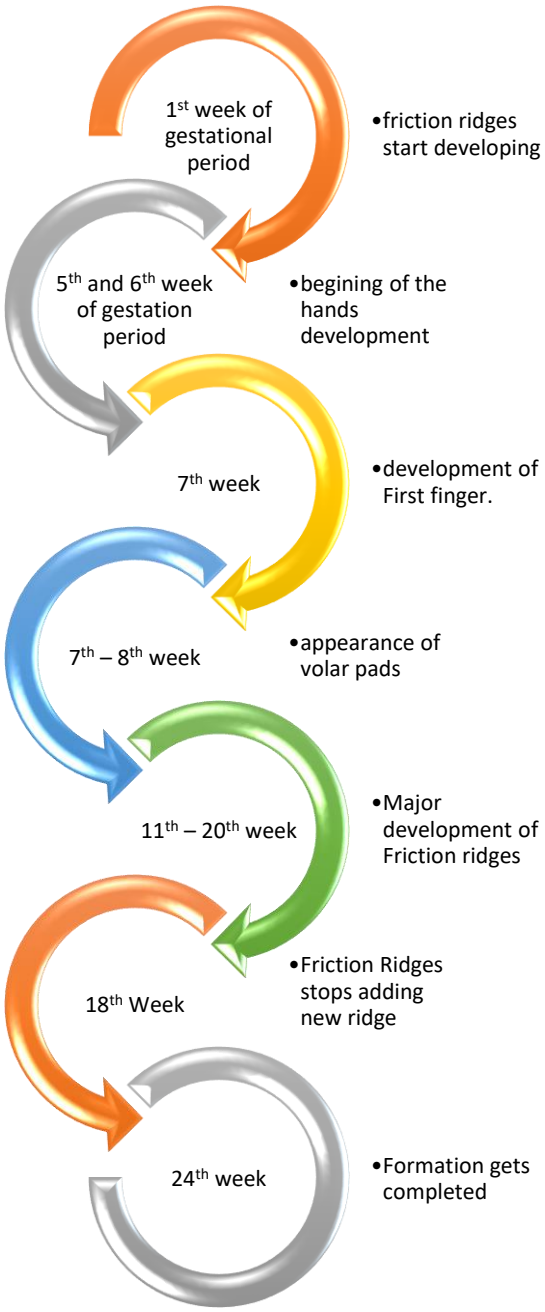


Figure 1.3: Development of Friction ridge

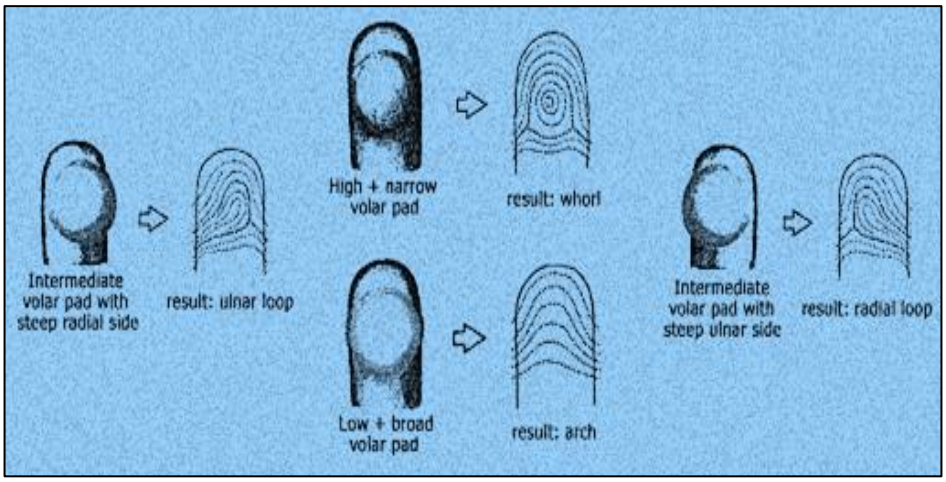


Figure 1.4: Pattern formation on fingers by Babbler, 1987 (Early prenatal volar pad development)

1.1.1. Formation of Finger impressions

The sweat glands are the main reason of leaving finger impressions on the surface/s. There are two types of sweat glands- apocrine and eccrine glands. Apart from the sweat glands, there is one more secretory gland which produces oil and waxy material called as sebaceous gland (Table 1.1). The eccrine sweat gland is the solitary skin protrusion on the friction ridge skin. Although sweat glands are found practically everywhere on the skin surface, the friction ridge skin contains the largest density of eccrine glands, with 2500- 3000/2.5 cm^2. The sweat is the main component in the fingerprint residue, it carries the 0.5% of organic matter, more than 98% of water, and 0.5 % of minerals (Table 1.2) (Hoover *et al*., 2021).

Apocrine glands

Apocrine glands, which are primarily present in the groin, external ear canal, armpits, and eyelids. As a result, their constituent parts are often not detected in high concentrations in fingerprint impression residues. Proteins, carbohydrates, cholesterol, lipids, ammonia, and iron are the primary components of this pungent discharge. As the friction ridges of the fingers (hands) are primarily covered by eccrine glands and the sebaceous gland secretions can be transferred by the touch of the hand with the face and scalp, and these secretions make up most of the fingerprint residue (Zito & Scharf, 2021).

Table 1.1: Composition of glands

Gland	Location	Composition	
		Organic constituents	**Inorganic constituents**
Sebaceous Glands	The highest concentration is on the forehead and the back; connected with hair roots; present all over the body, except for the palms of the hands and the soles of the feet.	Glycerides (30–40%) Squalene (10–12%) Sterol esters (2–3%) Sterols (1–3%) Fatty acids (15–25%) Wax esters (20–25%)	-
Eccrine glands	All over the body, but the only type of glands, on the palms of the hands and the soles of the feet.	Sugars, Creatinine, Amino acids, Proteins, Uric acid, Urea, Lactic acid, and Choline	Chloride, Metal ions (Na^+, K^+, Ca^{2+}), Bicarbonate, Ammonia, Sulphate, Phosphate
Apocrine glands	In the groin and the armpits; associated. with hair follicles around the genitals and mammary glands	Sterols, Carbohydrates, Proteins	Water (>98%), Iron

Eccrine glands

Simple tubular glands with ducts that open at the skin's surface are called eccrine sweat glands. The secretory component of the gland's coil is implanted in the dermis or hypodermis, and its duct extends through the epidermis. Water makes up 99.0 - 99.5% of the fluid produced by the eccrine sweat glands. The remaining components of sweat are amino acids, carbohydrates, immunoglobulin A, epidermal growth factor, potassium, sodium chloride, urea, lactate, ammonia, uric acid, creatinine, and creatine, as well as a few hormones, enzymes, and vitamins (Hoover *et al*., 2021).

Table 1.2: Composition of sweat

S. No	Organic components	S.No.	Inorganic components
1	Amino acids (120-720 ng),	8	Chlorides (0.27-1.5 pg. per print), sodium (<0.2-6.9 pg.)
2	Urea (90-720 ng; 400-1800 ng for fresh prints),	9	Sulphates (20-200 ng)
3	Uric acid	10	Phosphates
4	Lactic acid (9-10 pg.)	11	Ammonia (0-180 ng; 200-300 ng for fresh prints)
5	Sugars	12	Potassium (<0.2-5 pg.)
6	Creatinine	13	Calcium cation (0.03-0.3 pg.)
7	Choline		

Table 1.3: Composition of amino acids

Components of amino acids	Percentage
Serine	25-30%
Glycine	10-20%
Alanine	10%
Ornithine	10-15%
Threonine	5%
Aspartic acid	5%

Sebaceous Glands

Sebaceous glands are the second class of secretary glands in the skin. These are more prevalent on the face and scalp and are in areas with hair follicles. There are 400–800 sebaceous glands/cm^3 around the area of the skin. These glands are connected to the hair roots and secrete oil that shields the skin and hair. The major portion of lipids on the skin's surface are provided by the sebaceous gland through the production of sebum, which keeps moisture in and prevents the skin from drying out. Since sebaceous glands discharge into the hair canal, most of the sebum that reaches the skin's surface does so by wicking up the hair shaft. Sebum also includes antibacterial compounds, free fatty acids, glycerides, cholesterol, and hydrocarbons such as squalene and matrix metalloproteinases in addition to cell debris and lipids.

These components work together to create a cutaneous lipid film, which shields the skin from damage from the environment. Despite the absence of sebaceous glands on the palms, the hands frequently come into touch with the face and hair, making sebaceous gland secretions a common part of a finger impressions (Abebe *et al*., 2020; Hoover *et al*., 2021; Wertheim, 2011). The composition of finger impressions includes the natural secretions -sweat and sebum and other environmental factor which contaminates the finger impression and adds the other characteristics to it.

1.2. HISTORICAL DEVELOPMENT OF FINGERPRINTS

The study of fingerprints dates to the earlier civilizations. The exact person hence cannot be named who first time used the fingerprints for identification purpose. But the idea that fingerprints could be used for personal identification was first used by Sir William Herschel, district magistrate of Hooghly district, Bengal, 1858 (Barnes *et al*., 2011).

Ancient History:

In North-west China earthenware was found containing clear friction ridge impressions estimated to be 6000 years old. Thousands of years before BC, fingerprints were found on pottery as a mark and seal of the maker. Pre-historic cave wall etching found in Nova Scotia, Canada, showing a hand with ridge patterns sketched on it. Fingerprints were used as seals during Tong dynasty, China. The deeds were signed by means of fingerprints during Sung

period. Persian physician Rashid-al-Din Hamadani or ― Rashideddin‖ in his collections called Jami-al Tawarikh, commented on the Chinese practice of identifying people through fingerprints. Fingerprints along with palm prints known as ― PANJA were used for identification. In India, fingerprints were embossed on clay tablets and seals during Indus Valley Civilization. Slabs of clay were found in King Tut-en-khamen's tomb in Egypt. In ancient China, thumb prints were found on clay seals (Barnes *et al*., 2011).

From 17th to 20th Century:

Grew (1684) stated about the innumerable little ridges which are present in the equal size on the ends of the first joints of the fingers. His paper also revealed about the sweat pores referred as little fountain; epidermal ridges, and their arrangements.

Bidloo (1685) incorporated a diagram of friction ridges and pore structure in the human anatomy book, but was not able to discuss about the individuality of the friction ridges.

Malpighi (1685 - 86) discussed the function, form, and structure of the friction skin as a touchable organ and also mentioned the presence of spirals and loops in finger impressions but was not able to explain its importance. The thick layer of the skin was named after him as Malpighi layer.

Thomas Bewick (1753-1828): An English wood engraver and ornithologist, written numerous books with wood engravings of birds and other animals. Thomas Bewick left his mark on three woodcuts (created in 1809, 1818, and 1826), the last two of which included the legend "Thomas Bewick, his mark" (Herschel, 1916). Although the woodcuts were quite detailed, it is unclear if Bewick appreciated how important friction ridge skin is for individualization (Berry & Stoney, 2001) .

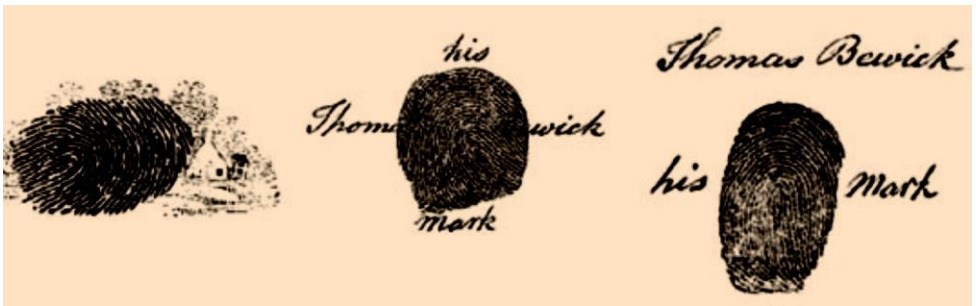


Figure 1.5: Finger marks published by Bewick

Dr. E. Purkinje (1823) was a professor at the University of Breslau in Germany, divided fingerprint patterns into nine categories and assigned each one a name in his 1823 thesis, "Commentary on the Physiological Examination of the Organs of Vision and the Cutaneous System" (Lambourne, 1984; Galton, 1892). Even though Dr. Purkinje only named the patterns, his work is essential because the Henry classification system was based on his nine pattern categories (Herschel, 1916; Galton, 1892).

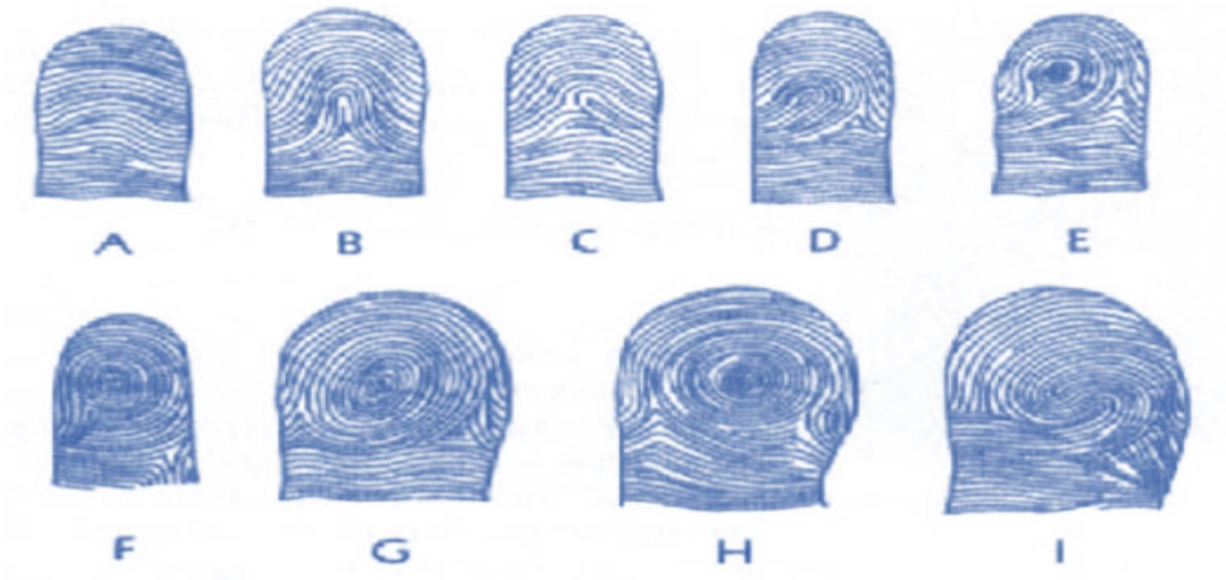


Figure 1.6: Purkinje's nine types of finger patterns. (A: Transverse curves, B: Central longitudinal stria, C: Oblique stria, D: Oblique sinus, E: Almond, F: Spiral, G: Ellipse or elliptical whorl, H: Circle or circular whorl, and I: Double whorl).

William Herschel (1858) was the first one person to investigate the persistence of friction ridge skin. The scientist was born in England and emigrated to Bengal, India, in 1853 at the age of 20 years. By asking Rajyadhar Konai to stamp his right hand on the back of a contract for road binders in 1858, he tried out the idea of using a handprint as a signature. The agreement was acknowledged and given legal standing. Thus, Konai's hand's accidental printing prompted the first authorized usage of friction ridge skin by a European. The Chief Magistrate of the Hooghly district, Jungipoor, India, first Person to use fingerprints on native contracts.

Henry Faulds (1880), a Scottish physician and scientist examined the fingerprints in depth and recognized their potential for personal identification. In an article "On the Skin-Furrows of the Hand," published in 1880, Faulds stated that fingerprints could be classified based on their ridge patterns and that the ridge details were distinctive and unique to everyone. He also

recognized the importance of fingerprints in medico-legal studies, stating that while photographs of people may change, friction ridges on the skin remain constant throughout a person's life. Faulds also emphasized the importance of locating fingerprints at crime scenes as a means of apprehending criminals.

Kollmann (1883) was a German anatomist and embryologist who in 1883 published a paper titled "The Peculiarities of the Fingerprint" in which he made several important observations regarding the development of friction ridges in the human embryo. Kollmann was the first to suggest that friction ridges were formed during foetal development due to topographical physical stressors on the skin and also proposed that the ridges were caused by the compression of the epidermis and dermis between the developing volar pads of the fingers and toes and the bony surfaces of the hands and feet (Large 1963). He also identified the presence and location of volar pads on the human hand and foot. These pads are temporary structures that form during foetal development and are thought to play a role in the formation of the ridges on the fingers and toes.

Thomas Taylor (1887), a British barrister and amateur criminologist published a book titled "The History and Philosophy of Finger-Print Identification" in 1887 mentioning the use of fingerprints for personal identification and criminal investigation. He described various cases in which fingerprints had been used to identify criminals, and he also suggested new methods for collecting and analysing fingerprint evidence. One of these methods involved taking impressions in wax from the hands of suspected persons and comparing them to marks left at a crime scene (Barnes *et al*., 2011).

Sir Francis Galton (1822-1911) published a book entitled "Fingerprints," in 1892 which included the first classification system for fingerprints. He also scientifically proved that fingerprints do not change over the course of an individual's lifetime and that no two fingerprints are the same. According to his calculations, the odds of two individual fingerprints being the same were 1 in 64 billion. The ridge characteristics or minutiae were also identified which are responsible for establishing the supremacy of fingerprints over Bertillon's anthropometric method of identification. In 1901, Galton's methods were adopted by Scotland Yard as the primary means of personal identification, and they quickly became standard practice in law enforcement around the world (Stigler, 1995).

Juan Vucetich (1858-1925) an Argentine police official who is credited with developing the first method for using fingerprints in criminal investigations and independently developed a

fingerprint classification system and began filing criminal fingerprints using the new system. This method was used to solve the *first murder case* in which fingerprints played a decisive role, **the Rojas murder case**, in 1892. By 1896, Argentina became the first country in the world to adopt fingerprinting as the primary method of criminal identification and abolish the use of anthropometry.

Sir Edward Henry (1850-1931), a British policeman who served from 1850 to 1931, and played an influential role in the advancement of fingerprinting as a method of criminal identification. In 1891, Henry began adding the left thumb impression to each anthropometric file card. In 1894, expanded the practice to include printing all ten fingers of each prisoner, and assigned two Bengali officers, **Khan Bahadur Azizul Haque** and **Rai Bahadur Hem Chandra Bose**, to study the classification problem. They eventually succeeded in setting up a classification system with 1,024 primary positions and secondary breakdowns in each. In 1897, fingerprints were adopted as the official method for the identification of criminals in British India. In December 1900, the Belper Committee recommended that the fingerprints of criminals be taken and classified by the Indian System, and these recommendations were implemented in 1901. The Indian system eventually replaced anthropometry, and the systems of Henry and Vucetich form the basis of most of the ten-digit classification systems used at present.

Chatterjee (1962) proposed the Edgeoscopy in 1962 as a method for identifying individuals by examining and comparing the characteristics of the edges of the ridges on their friction skin. These characteristics include the alignment and shape of individual ridge units and are unique and persistent throughout a person's life, although the size of the edges may vary with age. Chatterjee classified these characteristics into seven types, including straight, convex, peaked, table, pocket, concave, and angular edges. The visibility of these edges can be affected by the type of surface and ink used in creating the print.

1.3. FINGERPRINT

1.3.1. Characteristics of fingerprints

The fingerprint possesses certain common characteristics, collectively referred to as pattern area, type lines, delta, and core.

- **Pattern area**, found within loops or whorls, encompasses the core, deltas, and ridges that play a crucial role in fingerprint classification. It exists in all patterns, although it is not clearly defined in most arches.
- **Type lines** enclose the pattern areas in loops and whorls. These are the ridges that define the pattern area in loops and whorls, whereas arches do not exhibit type lines. They can be well-defined as two inner ridges that start parallel or run parallel to each other before diverging and covering the pattern area. They do not form continuous ridges but are often observed to separate.
- **Delta** occurs when a ridge splits into two, with the bifurcating arms, or when adjacent ridges running alongside each other diverge, creating a space within which the pattern is situated.
- The **core** represents the central point of the pattern and is approximately located at the centre of the fingerprint.

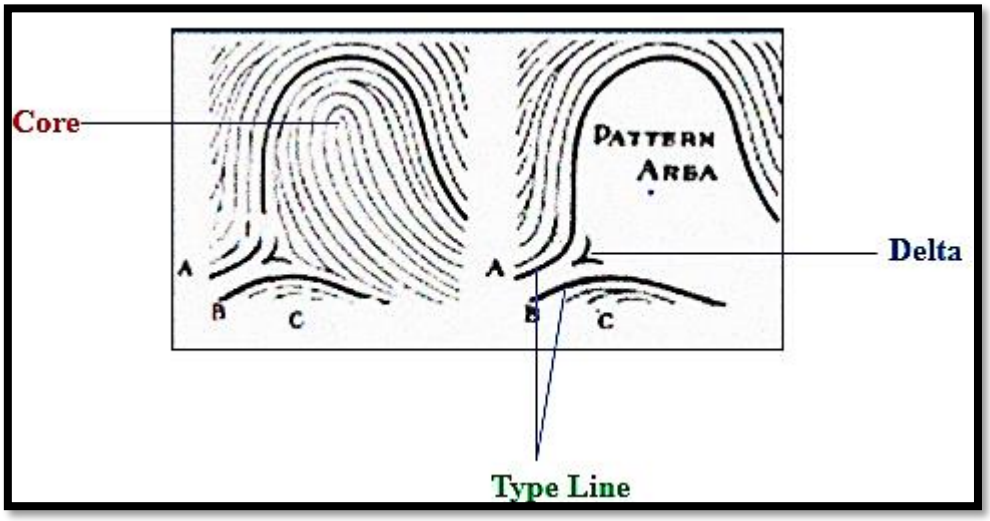


Figure 1.7: Fingerprints pattern characteristics

1.3.2. Classification of Fingerprints based on their pattern type

The ridges on the fingertips create distinctive patterns and crossing lines that allow for systematic classification. According to the Henry-Galton system of classification (Henry 1901), the fingerprint patterns can be divided into three distinct categories arch, loop, and whorl. Each of these groupings shares the same broad traits. In accordance with the more subtle variations between the patterns belonging to the same basic group, these patterns are

further separated into sub-groups. This is a class 1 characteristics of fingerprints. With time the classification of fingerprint has been updated. There are four types of fingerprint patterns (Figure 1.7).

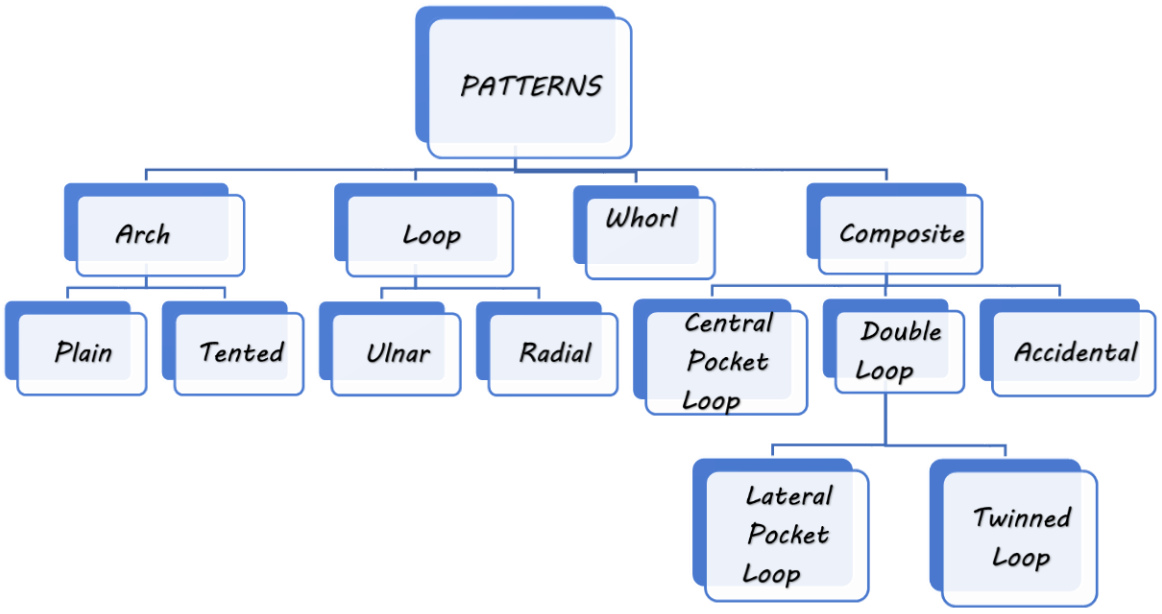


Figure 1.8: Types of fingerprints patterns

Arch

A ridge which enters from one side of the finger and exit to the other side with a formation of wave like structure. This type of pattern does not contain delta, and core. The arch pattern is of two into plain and tented arch (Figure-1.9). Plain arch is the simplest of all fingerprint patterns and easily distinguished. In plain arch the ridge pattern forms a wave like shape in the centre. The tented arch forms an upward rise in the middle of the wave (Sudha, 2012).

Figure 1.9: Types of arch a) Plain Arch b) Tented Arch

LOOP

It is a type of ridge pattern where the ridges start and end to the same side of the finger with slight bending to form loops (Figure 1.10). Necessary conditions of their formation are sufficient recurve, a delta and ridge count across a loop where a sufficient recurve may be defined as that part of a recurving ridge from the most exterior of the outermost ridge. Loop is sub-divided into two categories radial and ulnar (Kumar, 2021). Loop pattern which opens towards thumb is radial loop (Sudha 2012). The name radial is derived from the radius bone of the forearm as radius bone is present on the thumb side. Similarly, the loop patterns that open towards little finger (to the direction of ulna bone) is ulnar loop. (Anon 1984; Cowger 1992).

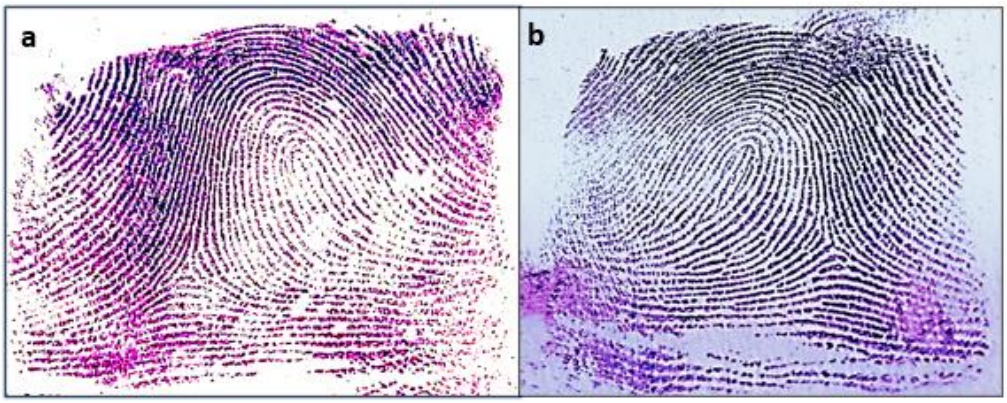


Figure 1.10: Types of loop a) Radial Loop b) Ulnar Loop

Whorl

This pattern forms when the ridges move into a circular shape having the core. The whorl has two deltas and at least one continuous ring, which may be spiral, oval, circular, or any variant of a circle (figure 1.11).

Figure 1.11: Whorl

Composite

It is a type of complex patterns in which two or more patterns are united in one. The composite patterns are sub characterized as central pocket loop, double loop and accidental (figure 1.12).

Central pocket loop

This pattern is almost same as loop pattern with additional central pocket. However, the ridge need not to be a part of the continuation ridge neither it should start from the beginning of the pattern.

Double loop

The pattern made up of two different loops are known as double loop. The pattern is of two types- Lateral pocket loop and twinned loop.

- **Lateral pocket loop**- This pattern type is characterized by the presence of two interlocked loops whose ridges when traced from the cores of the loops emerge on the same digital margin (radial or ulnar).
- **Twinned loop**- Ridges starting from two opposite directions entangled together forms 'S' like pattern. Here, one end of the finger and makes an upside-down loop and other ridges starting from another end of the finger forming a converted loop.

Accidental

An accidental pattern is a design that meets some of the criteria for two or more different types or a pattern that does not fit any one specific description. It could combine a loop with a central pocket loop, a loop with a whorl, a double loop with a central pocket loop, or other patterns. This pattern is found in about 2-3% of population hence, makes it a rare print.

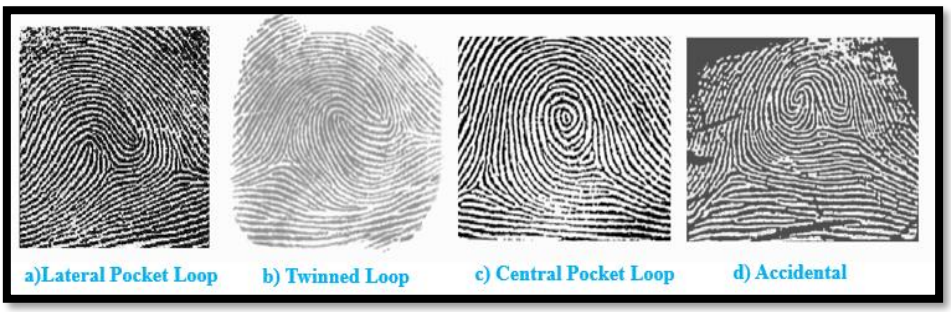


Figure 1.12: Composite patterns a) Lateral Pocket loop b) Twinned loop c) Central pocket loop d) Accidental

1.3.3. Ridge characteristics

Ridge characteristics refer to the unique features found in fingerprints that help distinguish one individual's prints from another. These characteristics are primarily formed by the ridges and furrows present on the skin's surface (Nath, 1991). Here are some key ridge characteristics found in fingerprints:

Ridge Endings: These occur when a ridge terminates abruptly without connecting to another ridge. They can be used to determine the overall flow and direction of the fingerprint pattern.

Bifurcations: Bifurcations happen when a ridge splits into two separate branches. These branching points provide important information about the fingerprint pattern and are commonly used for identification and classification purposes.

Trifurcation: Trifurcation is an uncommon ridge pattern where a ridge divides into three smaller ridges.

Ridge Enclosures: This characteristic occurs when a ridge forms a complete loop and surrounds an area within it. Ridge enclosures are commonly seen in loop patterns and can be helpful in distinguishing different types of loops.

Islands: Islands are small ridge formations that appear within a fingerprint pattern. They are isolated from the main ridge flow and can be useful in identifying and differentiating between different fingerprints.

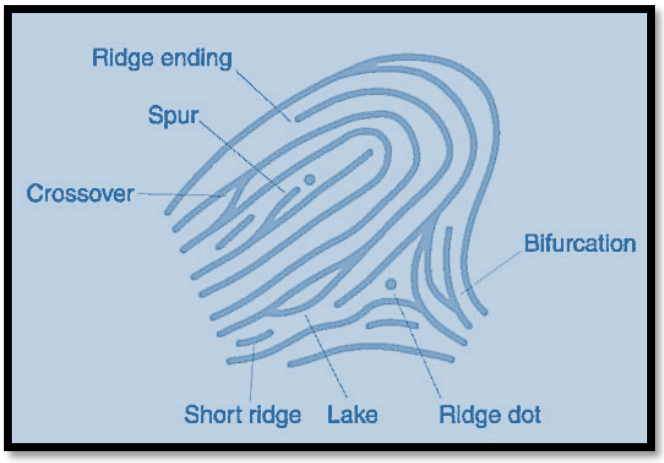


Figure 1.13: Ridge characteristics

Short Ridge Segments: These are small, fragmented sections of ridges that do not form continuous lines. Short ridge segments can occur due to breaks or interruptions in the ridge flow and can provide unique identifying characteristics.

Ridge Spur: A ridge spur is a small ridge that protrudes from the main ridge flow. Spur characteristics can be useful in determining the orientation and direction of the fingerprint pattern.

Interjunction: It refers to the connection between two neighbouring ridges through a brief diagonal ridge. This ridge connection is also commonly referred to as a crossover. These points are significant as they help define the ridge flow and can aid in identifying and classifying fingerprint patterns.

Intersection: It is also known as a changeover, occurs when two adjacent ridges exchange positions by crossing over each other.

These ridge characteristics, along with other details such as the overall pattern type (loop, whorl, or arch), ridge count, and spacing between ridges, are used by forensic experts and automated fingerprint recognition systems for fingerprint analysis, identification, and matching purposes.

1.3.4. Classification of fingerprints based on appearance

The fingerprints discovered at crime scene are classified as patent, plastic, and latent prints, even though all three varieties are sometimes referred to as latent prints (Figure 1.14).

1.3.4.1. Patent Prints

The word patent means visible. These prints are visible without any treatment. The visible prints are further classified as positive and negative impressions. Positive image is formed by the fingerprint ridges contaminated with a coloured substances such as ink, paint, blood etc. whereas negative prints are formed when fingerprint ridges remove the surface material such as dust and soot. The patent prints found at the crime scene can be directly analysed for the matching with the potential suspects either manually or using fingerprint analysis software.

1.3.4.2. Plastic Prints

Plastic prints can also be categorised under visible prints. These are the indented impressions caused be the contact of the finger with a malleable substance like wax, soap, clay which makes 3-D image of the impression. These impressions stay visible on the surface as long as there is sufficient contrast between the mark and its support. The fainted visible impressions need oblique light for better imaging. As these prints are also visible like patent prints hence, can be analysed directly after captured by camera either manually or using fingerprint analysis software.

1.3.4.3. Latent Prints

The word latent means invisible, hidden or dormant. Latent prints are the invisible prints that are commonly found at crime scene. As these prints are dormant in nature it must be developed using physical or chemical process to enhance the residue of latent prints. The latent fingerprints are the complex mixture of natural secretion of sweat, and contaminants from the environment. Since only eccrine glands cover the ridges of the hands, the secretions of these glands are present in every latent finger-mark at the time of deposition. Apocrine gland contamination is rare but could be significant in some crimes (such as crimes of a sexual nature, violent crime), whereas contamination by sebaceous gland secretions is frequently caused by actions like combing hair and touching the face (Boone, 2023).

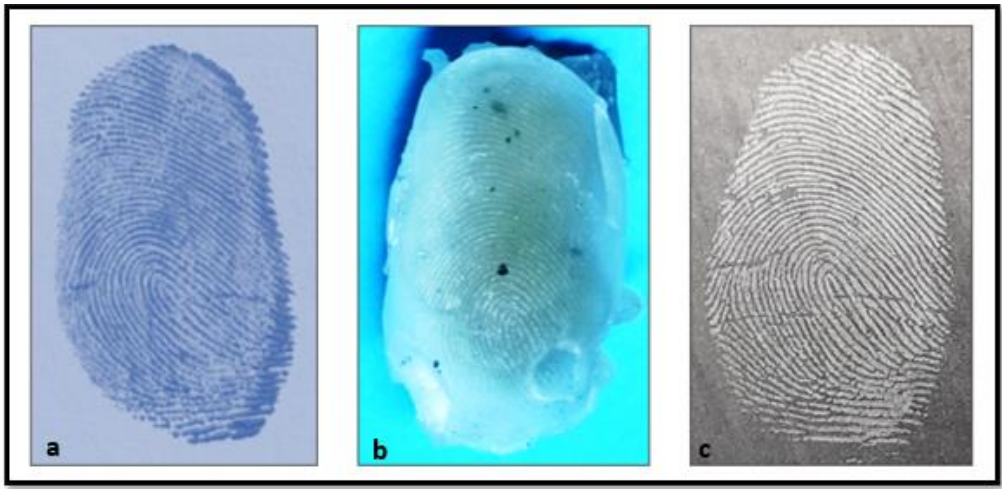


Figure 1.14: a) Patent b) plastic c) latent print developed using powder method

For an effective fingerprint detection, it is crucial to understand the main components of this accumulation. It is also crucial to be aware of the various environmental factors that could

affect this accumulation. Latent fingerprints must undergo further processing to become visible, in contrast to the other two categories of prints. Development, enhancement, or visualisation describe the process of making the latent prints visible and acceptable for comparison. Latent prints are developed using a variety of procedures and use of chemicals, powders, lasers, alternative light sources, and other physical techniques are a few of them. The development methods for latent impressions vary with the surface type, they are found on. Surface characteristics play a crucial role in this process. In 1995, Bobev conducted a study that highlighted several observations on latent fingerprints depending upon the different surface type. Although environmental conditions also influence these characteristics. Surfaces can be classified into three categories based on their ability to retain latent impressions:

1. Porous surfaces: These surfaces have small spaces or pores that allow liquid or air to pass through them. Examples include paper, cardboard, and unfinished wood. Latent impressions on porous surfaces are usually absorbed into the surface and are difficult to recover.
2. Non-porous surfaces: These surfaces do not have pores and do not allow liquids or air to pass through them. Examples include glass, metal, and plastic. Latent impressions on non-porous surfaces are usually deposited on the surface and can be recovered using various development techniques.
3. Semi-porous surfaces: These surfaces have some pores or spaces that allow some degree of liquid or air to pass through them. Examples include painted surfaces, varnished wood, and leather. Latent impressions on semi-porous surfaces can be recovered using specialized development techniques that take advantage of the surface properties.

1.3.5. Levels of Identification and Comparison of Fingerprint patterns

To ensure a more comprehensive approach to latent fingerprint identification, a holistic approach is needed. Persistence and uniqueness are the foundations of fingerprint science, and this applies not only to ridge flow and minutiae but also to other aspects of ridge structure. The identification process involves three levels of detail-

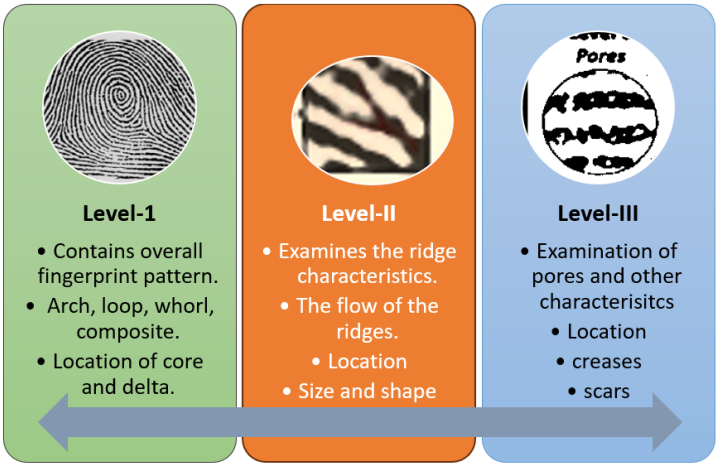


Figure 1.15: **Characteristic features of fingerprints identification at various level**

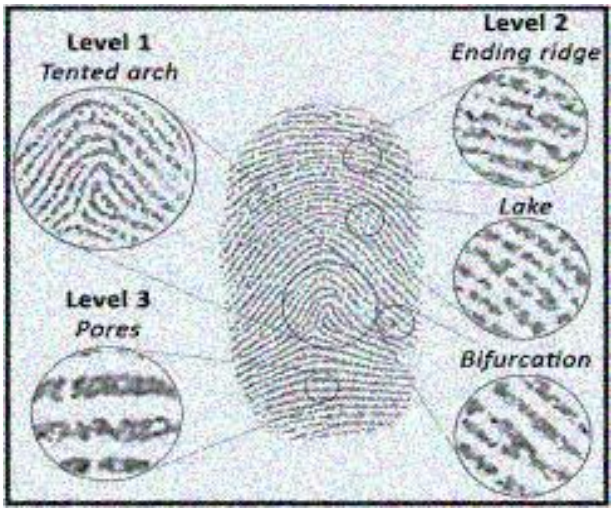


Figure 1.16: **Fingerprint pattern representing levels of characterization**

Experts must also consider the clarity of the print before forming an opinion. Although most experts currently rely on the number and sequence of ridge characteristics to explain identification, they should also consider these additional aspects for a more accurate and reliable identification process.

1.4. Traditional methods used for the latent fingerprints development

1.4.1. Iodine Fuming Method

The iodine fuming method is one of the oldest and most used methods for developing latent fingerprints on porous surfaces such as paper, cardboard, and unpainted wood. It is a simple, low-cost, and non-destructive method that relies on the chemical reaction between iodine

crystals and the fatty acids present in the oils and sweat secretions on the ridges of the latent fingerprints. The process of iodine fuming involves heating iodine crystals, which sublimate into a vapor that reacts with the oils and sweat secretions present in the latent fingerprint to produce a visible brownish color. The chemical reaction occurs due to the affinity of iodine for the unsaturated and double bonds present in the fatty acids (Yamashita *et al*., 2010).

The chemical reaction of the iodine fuming for fingerprint development is as follows-

$$2I_2 + 2H_2O \rightarrow 4H+ + 4I- + O_2 \quad (1.1)$$

In this reaction, iodine molecules (I_2) react with water (H_2O) to form hydronium ions (H^+) and iodide ions (I^-). The oxygen molecule (O_2) is a by-product of this reaction. When a non-porous surface is exposed to iodine fumes, the iodine reacts with the amino acids and fatty acids in the fingerprint, forming a complex that can be visualized as a brown or yellow-brown color. The method is non-destructive, as it does not alter the physical or chemical properties of the substrate on which the latent fingerprint is located. Additionally, iodine is a readily available and relatively inexpensive reagent. However, this method is not effective for developing latent fingerprints on non-porous surfaces such as metal or plastic, as the iodine fumes cannot penetrate the surface to react with the fatty acids in the latent fingerprints. Fumes can be hazardous if inhaled, making it necessary to take appropriate safety precautions when performing the fuming process.

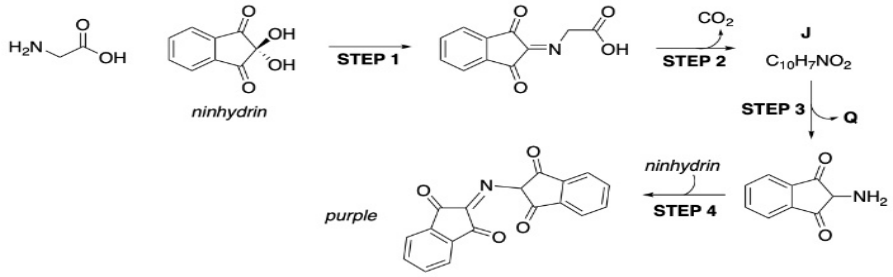
1.4.2. Powder Dusting Method

In this method, a fine powder is applied to the surface where the fingerprint is suspected to be present. The powder adheres to the sweat and oil residue left by the ridges of the finger, making the latent print visible. The powder used can be of different types, such as black, white, or coloured. The choice of powder depends on the surface being examined and the color of the surface. For example, black powder is commonly used on light-coloured surfaces, while white powder is used on darker surfaces (Gurvinder Singh Sodhi & Kaur, 2001). Coloured powders are used on surfaces with patterns or designs, where a contrast color is necessary to bring out the fingerprint details. Once the powder is applied, it is gently brushed away with a brush leaving the developed latent fingerprint visible. This method is inexpensive and can be used on various surfaces, including paper, cardboard, and rough surfaces. The powder dusting method has its limitations, it can only be used on dry surfaces

and may not be effective on oily or greasy surfaces. Also, the powder can sometimes damage or smudge the fingerprint, making it difficult to analyse.

1.4.3. Ninhydrin Method

The ninhydrin method is a commonly used chemical method for developing latent fingerprints on porous surfaces such as paper, cardboard, and other similar materials. Ninhydrin, a chemical reagent, reacts with amino acids present in the latent fingerprint residue to produce a purple-coloured compound known as Ruhemann's purple *(M. Wang et al*., 2017).



(1.2)

The ninhydrin method is sensitive, easy to use, and produces high-quality results. It has some restrictions, such as the requirement of heat, longer development time, and it can only be used on porous surfaces. The developed prints are also not very stable and can fade over time (Jasuja, Bumbrah, and Sharma 2016).

1.4.4. Silver Nitrate Method

It involves the reaction of silver nitrate with chloride ions in sweat residues to produce a visible silver chloride precipitate, which forms the fingerprint pattern. The silver nitrate method is a classic chemical technique for developing latent fingerprints on porous surfaces and is based on the reaction of silver nitrate with the chloride ions present in the sweat residues of fingerprints. The reaction forms a visible silver chloride precipitate that reveals the fingerprint pattern. The resulting fingerprint pattern is a black or brown image that is visible against the white or light-coloured background of the surface being tested.

$$AgNO_3 + Cl^- \rightarrow AgCl + NO_3^- \quad (1.3)$$

$$2AgCl \xrightarrow{hv} 2Ag + Cl^- \quad (1.4)$$

The silver chloride precipitate can be further enhanced by using a variety of reagents, such as sodium thiosulfate, which converts the silver chloride into a more stable silver sulphide. While the silver nitrate method can be effective in developing latent fingerprints on porous surfaces such as paper, cardboard, or fabric, it has several limits such as the silver nitrate solution is sensitive to light and can fade over time if not stored properly, making it difficult to obtain a clear image of the fingerprint for analysis. Additionally, the silver nitrate solution can produce background interference, particularly on paper or cardboard, where it can react with the substrate and produce a background color that may interfere with the visualization of the fingerprint.

There are several **disadvantages of traditional methods** of fingerprint development, such as-

1. *Limited effectiveness on certain surfaces*: Conventional methods of fingerprint development, such as dusting and chemical methods, are only effective on porous surfaces such as paper, cardboard, or wood. They may not be effective on non-porous surfaces such as metal, glass, or plastic.
2. *Degradation of fingerprints*: The development can sometimes degrade or destroy the fingerprint pattern, making it difficult to obtain a clear image for analysis.
3. *Time-consuming*: Traditional methods of fingerprint development can be time-consuming, particularly when developing fingerprints on large or complex surfaces.
4. *Hazardous chemicals*: The iodine fumes are toxic and can cause health problems if inhaled and the use of hazardous chemicals in ninhydrin which can pose health risks if not handled properly.
5. *Limited sensitivity*: It may not be sensitive enough to detect faint or partial prints, making it difficult to obtain a complete picture of the crime scene.
6. *Environmental concerns*: The process of evaporating and condensing the metal in a vacuum chamber may produce harmful gases, which can be environmentally damaging if not properly handled.
7. *Toxicity*: Silver nitrate is toxic and can be hazardous if not handled properly. It can cause burns and stains on skin and clothing and can be harmful if ingested or inhaled.

Hence, the conventional methods of fingerprint development have limitations that can hinder their effectiveness in certain forensic investigations. It is important for forensic investigators to consider the advantages and disadvantages of different fingerprint development techniques and select the most appropriate method for a given investigation.

Table 1.4: Advantages and disadvantages of various conventional latent fingerprinting techniques.

S.No.	Method	Advantage	Disadvantage
1.	Black Powder	Widely available and affordable; works on a variety of surfaces; produces sharp, clear prints.	Can be messy and difficult to clean up; may not work well on certain surfaces; may produce false positives.
2.	Magnetic Powder	Highly sensitive; produces prints on textured surfaces; easy to apply and remove.	May require special equipment such as a magnetic applicator; may not work well on non-magnetic surfaces.
3.	Fluorescent Powder	Can produce highly visible prints under UV light; can be used on a variety of surfaces.	Can be expensive; requires a UV light source; may produce false positives.
4.	Ninhydrin Method	Highly sensitive; can develop prints on old or degraded surfaces; can be used on a variety of surfaces.	May require a long development time; may produce background staining; may require special handling due to toxicity.
5.	Iodine Fuming	Simple and inexpensive, works on a variety of surfaces, produces visible prints.	Prints may fade quickly; may produce false positives; iodine is toxic and must be used with caution.
6.	Silver Nitrate	Produces highly visible prints; can be used on porous and non-porous surfaces; prints are more permanent than with other methods.	Requires a highly controlled environment to avoid contamination; may produce false positives; silver nitrate is toxic and must be used with caution.

1.5. ADVANCED METHODS FOR FINGERPRINT DEVELOPMENT

1.5.1. Cyanoacrylate Method

The cyanoacrylate fuming method, also known as the superglue fuming method is a technique used for developing latent fingerprints on non-porous surfaces from the late 1970s. The principle behind the cyanoacrylate fuming method is based on the reaction of cyanoacrylate vapours with the amino acids and fatty acids present in the latent fingerprints. Cyanoacrylate is a liquid monomer that is commonly used as a fast-drying adhesive. When heated, cyanoacrylate vaporizes and reacts with the moisture and organic material present in the latent fingerprint, resulting in a white, solid polymer that adheres to the ridges of the fingerprint. This makes the fingerprint visible and permanent (Madkour *et al*., 2017).

The process involves placing the non-porous item containing the latent fingerprints in a sealed chamber with a small amount of liquid cyanoacrylate in the form of a superglue gel or liquid. The cyanoacrylate is then heated, either by placing the chamber in a warm water bath or by using a specialized cyanoacrylate fuming chamber that heats the cyanoacrylate vapor. The heating process causes the cyanoacrylate vapor to adhere to the ridges of the fingerprint, forming a white, solid polymer that can be visualized and photographed. The resulting print is permanent and can be lifted using tape or lifted using other traditional methods. It may not be effective for developing fingerprints on highly porous surfaces, as the cyanoacrylate may penetrate too deeply into the material and not adhere to the ridges of the fingerprint and on surfaces that have been exposed to extreme heat or moisture, as this may cause the fingerprint to deteriorate.

1.5.2. Physical Developer Method

The physical developer method is a chemical method used for the development of latent fingerprints on porous surfaces such as paper, cardboard, and unfinished wood. It is often used when other methods, such as the cyanoacrylate fuming method, have been unsuccessful in developing prints. The physical developer solution contains silver nitrate, which reacts with the chloride ions present in the sweat residue of the fingerprint. The reaction produces a visible silver chloride deposit on the surface of the material, which forms the basis of the developed fingerprint. The process of developing fingerprints using the physical developer method involves several steps:

First, the surface is treated with a dilute solution of hydrochloric acid to remove any potential contaminants that could interfere with the reaction. Next, the surface is washed with distilled water to remove the acid. Then applied to the surface using a brush or spray bottle. The solution is left to react with any latent fingerprints for a few minutes, after which the surface is washed with distilled water again to remove excess physical developer solution. The surface is then treated with a solution of sodium thiosulfate, which acts as a fixative to stabilize the developed fingerprint. The sodium thiosulfate solution also removes any unreacted silver nitrate from the surface (Sodhi and Kaur 2016). The final result is a visible and permanent image of the latent fingerprint. The physical developer method is effective on porous surfaces but is not suitable for non-porous surfaces such as glass, plastic, or metal.

1.5.3. Multi-Metal Deposition

The multi-metal deposition (MMD) method is a technique used for developing latent fingerprints on non-porous surfaces such as metal, glass, or plastic. It involves the deposition of multiple metal layers onto the surface containing the latent fingerprint to enhance its visibility (Gao *et al*., 2009; Yamashita *et al*., 2010). The chemical structure of the MMD method for fingerprint development is not applicable as it is a physical technique rather than a chemical reaction. The method involves the following steps-

1. *Surface preparation*: The non-porous surface containing the latent fingerprint is cleaned and prepared for the MMD process. This can involve removing any contaminants, such as dirt or oil, and roughening the surface to promote adhesion of the metal layers.
2. *Metal deposition*: The MMD method involves the deposition of multiple metal layers onto the surface containing the latent fingerprint. The first layer is typically a thin layer of a reactive metal, such as zinc or aluminium, which reacts with the surface to form a bond. This is followed by the deposition of a layer of a non-reactive metal, such as gold or silver, which enhances the visibility of the fingerprint. Additional layers of non-reactive metals may be added to further improve the visibility.
3. *Visualization of the fingerprint*: Once the metal layers have been deposited, the fingerprint can be visualized using a variety of techniques, such as oblique lighting, SEM imaging, or chemical treatments (Sodhi and Kaur 2017).

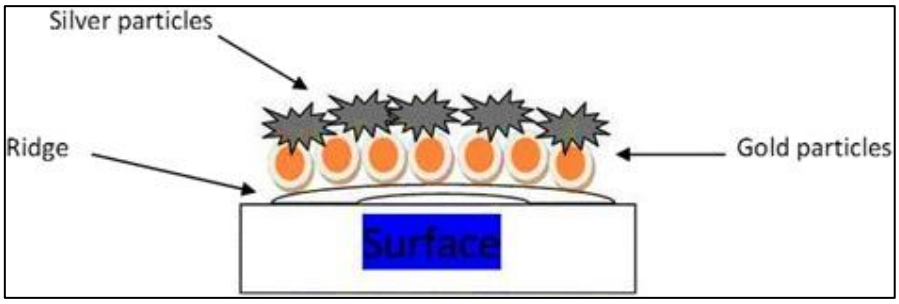


Figure 1.17: Multimetal deposition reaction mechanism

The MMD method is a highly sensitive and effective technique for developing latent fingerprints on non-porous surfaces. However, the process can be time-consuming and requires specialized equipment, making it more expensive than other fingerprints.

1.5.4. Vacuum Metal Deposition

Vacuum metal deposition (VMD) is a technique used for developing latent fingerprints on non-porous surfaces such as metal, glass, or plastic. It involves the deposition of a thin layer of metal onto the surface containing the latent fingerprint to enhance its visibility (Jones *et al*., 2001). The chemical structure of the VMD method for fingerprint development is not applicable as it is a physical technique rather than a chemical reaction. The method involves the following steps-

- *Surface preparation*: The non-porous surface containing the latent fingerprint is cleaned and prepared for the VMD process. This can involve removing any contaminants, such as dirt or oil, and roughening the surface to promote adhesion of the metal layer.
- *Metal deposition*: The VMD method involves the deposition of a thin layer of metal onto the surface containing the latent fingerprint. This is typically done using a vacuum deposition system, which involves the evaporation of the metal in a vacuum chamber, and the subsequent condensation of the metal onto the surface. The metal layer can be gold, silver, or other metals.
- *Visualization of the fingerprint*: Once the metal layer has been deposited, the fingerprint can be visualized using a variety of techniques, such as oblique lighting, SEM imaging, or chemical treatments.

The process can be time-consuming and requires specialized equipment, making it more expensive than other fingerprint development techniques.

1.5.5. Small Particle Reagent

The small particle reagent (SPR) method is a technique used for developing latent fingerprints on porous surfaces such as paper, cardboard, or fabrics. It involves the use of a suspension of fine particles in a liquid solution to adhere to and visualize the fingerprint. The chemical structure of the SPR method for fingerprint development is not applicable as it is a physical technique rather than a chemical reaction. The SPR suspension is made by mixing a fine powder, such as zinc oxide (ZnO) or titanium dioxide (TiO_2), with a liquid solution, such as detergent or water. The resulting suspension is then sonicated or stirred to break up any large particles and create a homogeneous suspension. The SPR suspension is then applied to the porous surface containing the latent fingerprint. This can be done by spraying, brushing, or dipping the surface into the suspension. The suspended particles adhere to the sweat and oils in the fingerprint, making it visible. The fingerprint can be visualized under a UV light or other light sources (Jasuja, Singh, and Sodhi 2008; Jasuja, Bumbrah, and Sharma 2016).

The SPR method is a sensitive and reliable technique for developing latent fingerprints on porous surfaces. However, it is not effective for non-porous surfaces, and the choice of the suspension used can affect the quality of the fingerprint developed. There are different variations of the SPR method that have been developed to improve the effectiveness of this technique like double-stick method, magnetic particle method, coloured particle method, Nano-SPR Method.

All the above **advanced methods and techniques** used for fingerprint development has several **disadvantages**, including-

1) *Limited applicability*: The SPR method is only effective on porous surfaces such as paper, cardboard, or wood. It may not be effective on non-porous surfaces such as metal, glass, or plastic. While VMD can produce high-quality images of latent fingerprints, the method may not work well on fingerprints that have been aged or degraded over time, limiting its applicability in certain forensic investigations.
2) *Environmental concerns*: The chemicals used in the SPR method, such as molybdate and lead acetate, can be toxic and pose environmental concerns if not properly disposed of.

3) *Time-consuming*: The SPR method can be time-consuming as it requires several steps, including preparing the reagents, applying the solution to the surface, and rinsing and drying the surface before visualizing the fingerprints.
4) *Limited sensitivity*: The SPR method may not be sensitive enough to detect faint or partial prints, making it difficult to obtain a complete picture of the crime scene.
5) *Background interference*: The SPR method may produce background interference, particularly on porous surfaces where the SPR solution can react with the substrate and produce a background color that may interfere with the visualization of the fingerprint.
6) *Cost*: The equipment required for VMD is expensive, making it a costly method for developing fingerprints compared to other techniques.

To overcome the issues mentioned above, a better method is needed to develop the latent fingerprint impressions. Hence, Nanoparticles were used by the scientists for enhanced imaging of latent finger impressions.

1.6. NANOPARTICLES IN LATENT FINGERPRINTING

1.6.1. Nanoparticles

Nanoparticles are the particles that are extremely small in size, typically measuring between 1 and 100 nanometres (nm) in diameter making them 1000 times smaller than a human hair (Gupta *et al*., 2023). To put that into perspective, a single strand of human hair can be up to 100,000 nanometres in diameter. Nanoparticles are of interest to scientists and engineers because their small size gives them unique properties and behaviours that are not seen in larger particles of the same material (Pande & Bhaskarwar, 2015). Nanoparticles can be made of a variety of materials including metals, polymers, and ceramics, and they can be engineered to have specific physical, chemical, and biological properties (Hasan 2014). They are used in various applications, including electronics, medicine, energy production, and environmental remediation. Some examples of their use include targeted drug delivery, water purification, and the development of more efficient solar panels. There is also ongoing research into the potential health and environmental risks associated with the production and

use of nanoparticles, as their small size can allow them to penetrate cells and tissues in ways that larger particles cannot.

Nanotechnology is also the evolving field in forensic science, the advancement of emergent techniques of nanoparticles being unified with latent fingerprinting. The size of nanoparticles made them unique and have adjustable mechanical, electrical, and optical properties. The application of nanoparticles on latent finger marks directed to successful development and detection due to the physical affinity of the nanoparticles with the finger mark residue like sweat, sebum or other contaminants.

1.6.2. Nanoparticles used in latent fingerprint

Nanoparticles can be classified into seven broad categories, based on their composition, size, shape, and properties.

1.6.2.1. Metal nanoparticles

Metals are lustrous, malleable and ductile in nature, they are good conductor of heat and electricity. Metal nanoparticles are commonly used for the development of latent fingerprints due to their large surface area, high sensitivity and specificity to fingerprint residues. These nanoparticles can be synthesized in various sizes and shapes, and their optical properties can be tuned to enhance their interaction with the fingerprint residue. Metal nanoparticles can interact with the amino acids and fatty acids in the print residue, resulting in a visible color change or fluorescence, which can reveal the fingerprint pattern. Gold, silver, zinc and copper are commonly nanoparticles used in fingerprint development due to their high sensitivity to light.

In gold nanoparticle-based method, gold nanoparticles are synthesized and functionalized with a cationic surfactant, which allows them to bind to the negatively charged amino acids and fatty acids in the print residue. The nanoparticles are then applied to the surface containing the latent fingerprint, and a reducing agent is used to trigger a chemical reaction that results in the deposition of the gold nanoparticles on the print residue, making it visible.

Silver nanoparticles have high sensitivity and can be synthesized in different shapes and sizes, while copper nanoparticles have been shown to be effective in developing fingerprints on porous surfaces.

Copper nanoparticles can be used for the detection of latent fingermarks on various surfaces as powder dusting technique. On a variety of nonporous surfaces, the green tea extract-coated CuO nanoparticles favourably improved the formation of latent finger impression (Bhagat *et al*., 2020).

Zinc is an essential trace element in the human body and is found in sweat, which makes it a potential target for fingerprint analysis. Zinc nanoparticles have several advantages for fingerprint development, including their high surface area, biocompatibility, and low toxicity. They are also stable, easily synthesized, and can be functionalized to enhance their interaction with the fingerprint residue. One method for using zinc nanoparticles for fingerprint development involves functionalizing them with a surfactant that has a high affinity for amino acids and fatty acids in the print residue. The functionalized nanoparticles are then applied to the surface containing the latent fingerprint, and a reducing agent is used to trigger a chemical reaction that results in the deposition of the zinc nanoparticles on the residue of finger impression. Recent studies have shown that zinc nanoparticles can be used to develop latent fingerprints on various surfaces, including plastic, glass, and paper. They have also been shown to have high sensitivity and selectivity for fingerprint residues, with potential applications in forensic investigations and criminal justice. zinc nanoparticles offer a promising alternative to traditional fingerprint development methods and may provide new opportunities for forensic investigations. However, further research is needed to optimize the synthesis and functionalization of zinc nanoparticles and to evaluate their effectiveness on different types of surfaces and in various environmental conditions.

1.6.2.2. Non-Metal nanoparticles

They are non-lustrous, non-malleable and non-ductile in nature, and act as insulators. Non-metal nanoparticles are used in various applications, such as electronics, energy storage, and biomedical imaging (Bhatia & Bhatia, 2016). Carbon nanoparticles, such as carbon nanotubes and graphene, are highly sensitive to changes in conductivity and have been used to develop sensitive sensors for detecting fingerprints. Carbon-based nanoparticles, such as graphene oxide and carbon dots, have been studied for their potential use in the development of latent fingerprints. Graphene oxide is a two-dimensional material that has a high surface area and excellent electrical conductivity. These properties make graphene oxide suitable for developing high-quality latent fingerprints. Carbon dots are also promising candidates for the

development of latent fingerprints. These nanoparticles have unique fluorescent properties that allow for the development of latent fingerprints with high contrast and resolution.

1.6.2.3. Metalloid nanoparticles

Metalloids exhibits the external characteristics of a metal, but behaves chemically more as a non-metal. They are another class of nanoparticles that have been explored for use in latent fingerprint development. Silica is a common mineral that is biocompatible and inert, making it a safe and effective material for forensic applications. Silica nanoparticles can be functionalized with specific chemical groups that can selectively bind to the amino acids and fatty acids in the print residue, enabling the visualization of latent fingerprints. One method for using silica nanoparticles for fingerprint development involves functionalizing them with a fluorescent dye that can be excited with a specific wavelength of light, allowing for the detection and visualization of the fingerprint pattern. Silica nanoparticles have several advantages for fingerprint development, including their high surface area, biocompatibility, and ease of functionalization. They are also stable, easily synthesized, and can be customized to target specific types of fingerprint residues. Recent studies have shown that silica nanoparticles can be used to develop latent fingerprints on various surfaces, including glass, metal, and plastic. They have also been shown to have high sensitivity and selectivity for fingerprint residues, with potential applications in forensic investigations and criminal justice. silica nanoparticles offer a promising approach for the development of latent fingerprints, with potential advantages over traditional fingerprint development methods. However, further research is needed to optimize the synthesis and functionalization of silica nanoparticles and to evaluate their effectiveness on different types of surfaces and in various environmental conditions.

1.6.2.4. Polymer nanoparticles

These are nanoparticles made of polymers, such as polyethylene glycol (PEG) and poly (lactic-co-glycolic acid) (PLGA). They are commonly used in drug delivery systems due to their biocompatibility and ability to encapsulate drugs. Conjugated polymers like poly-p-phenylene vinylene are called as optical imaging polymer having chemical and properties which makes it appropriate fluorescent substantial in the development of fingerprints (J. Li *et al*., 2013). It can lead to high resolution, increased sensitivity, and selectivity in the imaging of latent fingerprints (LFPs) compared to those developed by traditional methods.

1.6.2.5. Quantum dots

These are the nanoparticles made up of semiconducting materials, such as cadmium selenide (CdSe) and indium phosphide (InP). They have unique optical properties and are used in various applications, such as biomedical imaging and solar cells. Quantum dots are fluorescent semiconductor nanoparticles that emit light in response to ultraviolet light, which can be used to visualize fingerprints. Quantum dots are semiconductor nanoparticles that have unique photophysical properties, such as size-tuneable emission, high quantum yield, and excellent photostability. These properties make quantum dots suitable for various applications, including biomedical imaging and sensing. Quantum dots have also been investigated for their potential use in developing latent fingerprints. These nanoparticles can develop high-quality latent fingerprints with a high signal-to-noise ratio.

1.6.2.6. Lipid nanoparticles

These are nanoparticles made of lipids, such as liposomes and solid lipid nanoparticles (SLNs). They are commonly used in drug delivery systems and gene therapy due to their ability to encapsulate hydrophobic drugs and protect them from degradation (Shukla *et al*., 2021).

1.6.2.7. Magnetic nanoparticles

These are nanoparticles made of magnetic materials, such as iron oxide and cobalt. They are used in various applications, such as magnetic resonance imaging (MRI), drug delivery, and magnetic hyperthermia. Magnetic nanoparticles, such as iron oxide, are used in magnetic fingerprint powder formulations that can be selectively attracted to the iron content in sweat and oils in fingerprints.

1.6.3. Approaches to Synthesise Nanoparticles

Bottom-up and Top-down are two different approaches to nanoparticle synthesis.

1.6.3.1. Bottom-up nanoparticle synthesis

Bottom-up synthesis of nanoparticles involves the assembly of smaller building blocks (such as atoms, molecules, or precursors) into larger structures with specific size, shape, and composition. This approach offers greater control over the properties of the final nanoparticles compared to top-down synthesis, which involves breaking down bulk materials into smaller structures. Applications of bottom-up synthesized nanoparticles include

nanocomposites, catalysts, drug delivery systems, photonics, energy storage and conversion, and sensors.

The most common bottom-up synthesis methods for nanoparticles include chemical reduction, precipitation, sol-gel processing, and self-assembly. The choice of method depends on the desired properties of the final nanoparticles and the precursors used.

- *Chemical reduction*: involves the reduction of metal ions to form metal nanoparticles in solution.
- *Precipitation*: involves the formation of nanoparticles from a precipitate of a metal salt or other material in solution.
- *Sol-gel synthesis*: This method involves the precipitation of a solid material from a solution, often through the controlled hydrolysis of a metal-organic precursor (Bokov *et al*., 2021).
- *Self-assembly*: involves the spontaneous organization of nanoparticles into a structured arrangement through interparticle interactions.
- *Hydrothermal synthesis*: involves the formation of nanoparticles through a high-pressure and high-temperature reaction in aqueous solution.
- *Physical vapor deposition (PVD)*: This method involves depositing material onto a substrate through physical processes, such as thermal evaporation or sputtering.
- *Chemical vapor deposition (CVD)*: This method involves depositing material onto a substrate through chemical reactions that occur in a vapor phase.
- *Molecular beam epitaxy (MBE)*: This method involves depositing material onto a substrate using a beam of neutral atoms or molecules.
- *Atomic layer deposition (ALD)*: This method involves the sequential exposure of a substrate to precursors that react to form a thin film of material.
- *Liquid phase synthesis*: This method involves the synthesis of nanoparticles in a liquid medium, often with stabilizing agents or surfactants.

Each of these methods has its own advantages and limitations, and the choice of method will depend on the specific requirements of the desired nanoparticle system, including size, shape, composition, and surface properties (Goyal, 2017). These methods can be used alone or in combination to synthesize nanoparticles with specific properties and potential applications in various fields, such as energy, electronics, and medicine.

1.6.3.2. Top-down nanoparticle synthesis

Top-down nanoparticle synthesis refers to the production of nanoparticles by reducing the size of bulk material through physical or chemical methods. This approach contrasts with bottom-up synthesis, which involves the self-assembly of nanoparticles from smaller building blocks. Some common methods of top-down synthesis include high-energy ball milling, laser ablation, and electrochemical etching. These methods can produce nanoparticles with well-defined sizes, shapes, and compositions, which are important for various applications in fields such as electronics, energy, and medicine. The top-down synthesis techniques are-

- *Laser ablation*: This method uses a laser to ablate a bulk material, producing nanoparticles of various sizes and shapes.
- *Electrochemical synthesis*: It involves the formation of nanoparticles through an electrochemical reaction on an electrode.
- *Milling*: A mechanical method that involves grinding a bulk material using a milling tool, such as a ball mill or planetary mill. This method can produce nanoparticles with sizes ranging from tens to hundreds of nanometres.
- *Lithography*: A process of patterning a surface with the help of light or electrons. This method is commonly used in the semiconductor industry to produce nanoparticles with precise sizes and shapes.
- *Chemical etching*: A method that involves selectively removing material from a bulk sample using a chemical solution. This process can be used to produce nanoparticles with controlled sizes and shapes.
- *Plasma synthesis*: A method that involves using plasma to break down a bulk material into smaller particles. This method is commonly used to produce metallic nanoparticles.

Top-down nanoparticle synthesis has the ability to produce nanoparticles in large quantities, and its ability to control the size and shape. But this method faces difficulty in producing nanoparticles with uniform size and shape, and the potential for introducing impurities during the synthesis process.

Nowadays, environmental concerns have catalysed a paradigm shift towards more ecologically responsible practices in the realm of nanoparticle synthesis. Hence, it raised the

demands of green synthetic approaches of nanoparticles in order to eliminate or minimize the harmful impact of chemical used in the synthesis of nanoparticles.

1.6.4. Green synthesis of nanoparticles

Green synthesis of nanoparticles involves the use of eco-friendly and biocompatible materials and methods to produce nanoparticles, which avoids the use of hazardous chemicals and energy-intensive processes associated with conventional synthesis methods (Anchani *et al*., 2023). This approach utilizes natural sources such as plants, bacteria, and fungi, which contain phytochemicals, enzymes and biomolecules that can reduce and stabilize metal ions, leading to the formation of nanoparticles. Green synthesis offers numerous advantages, including low-cost, high yield and the possibility of producing nanoparticles with tailored properties suitable for specific applications. This approach has gained much attention in recent years due to its potential to address some of the major challenges associated with traditional synthesis methods, such as toxicity, high cost, and low yield. Green synthesis represents a promising area of research for the development of safe and efficient nanoparticles, and it is expected to have a significant impact on the fields of medicine, electronics, and environmental science. There are various green synthesis approaches for nanoparticles, which can be broadly categorized into the following categories:

- *Plant extract-mediated synthesis*- In this approach, plant extracts are used as reducing agents to convert metal ions into nanoparticles. The phytochemicals present in the plant extracts such as polyphenols, flavonoids, and terpenoids act as reducing agents and capping agents, preventing agglomeration, and stabilizing the nanoparticles. The synthesis process is simple, cost-effective, and can produce nanoparticles with controlled morphology and size.
- *Microbial-mediated synthesis*- In this process, microorganisms such as bacteria, fungi, and yeast are used to produce nanoparticles. These microorganisms produce enzymes and other biomolecules that can reduce and stabilize metal ions, leading to the formation of nanoparticles. Microbial mediated synthesis can produce nanoparticles with a high yield, and the process can be easily scaled up for large-scale production.
- *Enzyme-mediated synthesis*- Enzymes such as lipases, proteases, and cellulases can be used to synthesize nanoparticles. Enzymes act as reducing agents, and they can

also stabilize nanoparticles by forming a protective layer around them. They can produce nanoparticles with a narrow size distribution, and the process is relatively simple and cost-effective.

- *Green solvents-mediated synthesis*- green solvents such as water, ethanol, and glycerol are used as reducing agents and solvents for the synthesis of nanoparticles. These solvents are non-toxic and environmentally friendly, making them an ideal choice for green synthesis. It can produce nanoparticles with a high yield and controlled size and shape.
- *Bio-waste mediated synthesis*- Biomass waste materials such as fruit peels, tea leaves, and sawdust are used as reducing agents for the synthesis of nanoparticles. These waste materials contain natural reducing agents such as polyphenols and tannins, which can effectively reduce metal ions and stabilize nanoparticles. It is a cost-effective and eco-friendly method for producing nanoparticles.

Apart from offering a sustainable and eco-friendly alternative to conventional synthesis methods, these approaches have proven to produce nanoparticles with controlled size, shape, and morphology can be easily scaled up for large scale production.

1.6.5. Characterization of Nanoparticles

There are several techniques for the characterization of nanoparticles, depending on the properties of the nanoparticles and the information required. Some of the common techniques are:

1. *Fourier Transform Infrared Spectroscopy (FTIR)*: This technique is used to study the surface chemistry of nanoparticles. FTIR can provide information on the functional groups and chemical bonds present on the surface of the nanoparticles.
2. *Raman Spectroscopy*: This technique is used to study the vibrational modes of nanoparticles. It can provide information on the chemical composition, structure, and size of the nanoparticles.
3. *Scanning Electron Microscopy (SEM)*: This technique is like TEM, but it provides a three-dimensional image of the nanoparticles. SEM is particularly useful for studying the surface morphology and size distribution of nanoparticles.

4. *Transmission Electron Microscopy (TEM)*: This technique involves the use of a high-resolution electron microscope to study the size, shape, and structure of nanoparticles. TEM can provide information on individual nanoparticles and their distribution.
5. *Dynamic Light Scattering (DLS)*: This technique is used to measure the size distribution of nanoparticles in a liquid sample. It is based on the Brownian motion of nanoparticles in solution and can provide information on the hydrodynamic radius of nanoparticles.
6. *X-ray Diffraction (XRD)*: This technique is used to determine the crystal structure and composition of nanoparticles. It involves the measurement of the diffraction pattern of X-rays that have interacted with the nanoparticles.
7. *Atomic Force Microscopy (AFM)*: This technique is used to study the size, shape, and surface morphology of nanoparticles. AFM can provide high-resolution images of nanoparticles on a variety of surfaces.

1.6.6. Applications of nanoparticles in Dermatoglyphics

Nanoparticles have several applications in fingerprint analysis, including-

1. *Development of latent fingerprints*: Nanoparticles can be used to develop latent fingerprints that are not visible to the naked eye. For example, metal nanoparticles can be used in a solution to reveal latent prints by binding to amino acids and fatty acids in the print residue.
2. *Enhancement of fingerprint contrast*: Nanoparticles can be used to enhance the contrast of fingerprint impressions on a surface. For example, silica nanoparticles functionalized with specific chemical groups can selectively bind to the print residue and increase the contrast of the fingerprint.
3. *Identification of chemical composition*: Nanoparticles can be used to identify the chemical composition of the fingerprint residue. For example, quantum dots can be used to label specific amino acids and fatty acids in the print residue, allowing for more precise analysis and identification.

Nanoparticles have the potential to improve the sensitivity, selectivity, and resolution of fingerprint analysis, making it easier to identify suspects and solve crimes.

In addition to these applications, nanoparticles have the potential to revolutionize many areas of science and technology. Researchers are exploring the use of nanoparticles in the

development of more efficient solar cells, and in the creation of new materials with unique properties. Nanoparticles are also being studied for their potential in quantum computing, where their small size and unique properties could make them ideal building blocks for quantum devices.

CHAPTER-2

REVIEW OF LITERATURE

2. LITERATURE REVIEW

2.1. FORENSIC SIGNIFICANCE OF FINGERPRINTS

Fingerprint evidence stands as one of the most conclusive methods for individual identification, attributed to the unique nature of each fingerprint. The development of fingerprints takes place in the second trimester of fetal growth, and interestingly, they are already present on a newborn's palms, fingers, soles, and toes. Once formed, fingerprints remain consistent throughout a person's lifetime, aside from their proportional enlargement alongside bodily growth **(Moenssens & Meagher, 2012)**. This integrity persists until the skin deteriorates post-mortem. Despite the apparent visual similarities that fingerprints can bear, it remains an established fact that no two individuals, even genetically identical twins, have ever displayed identical fingerprints anywhere in the world. Scrutinizing the minutiae of two fingerprint samples under expert examination reveals countless variations in the ridge features spread across the fingerprint's surface at specific points. The core purpose of a criminal investigation revolves around identifying the perpetrator, and fingerprints offer a scientific clue that accomplishes not only positive identification but also distinctively eliminates any link to the broader population.

Among all forensic sciences, the discipline of fingerprint identification stands prominently, having dutifully served governments across the globe for nearly 120 years in accurately identifying criminals. Remarkably, in the billions of fingerprints analyzed, not a single instance of identical prints has emerged. This uniqueness forms the very bedrock of criminal history establishment within every law enforcement agency, establishing fingerprints as the paramount forensic evidence employed universally. In fact, fingerprints hold their place as the most widely utilized method in forensic science worldwide. Across numerous jurisdictions, the volume of cases involving fingerprint examinations surpasses the combined total of all other forms of forensic analysis. This prevalence only continues to grow, as tens of thousands of individuals are consistently added to the fingerprint database. When collected from crime scenes, fingerprints not only point towards additional suspects but also yield a greater wealth of evidence in court compared to the collective impact of all other forensic methodologies combined. Thus, the science of fingerprint identification maintains its unparalleled status as the preeminent approach for personal identification and criminal investigation.

Identification involves the comparison of a suspect's fingerprints with incidental prints collected from a crime scene. This process seeks to ascertain whether a connection can be established by analyzing a minute section of ridge patterns found at the crime scene in relation to those of the suspect. It's worth noting that classification is not a necessity for this comparative analysis. Fingerprints have served as a distinctive marker of individuality since their official adoption and subsequent formal classification. The study of fingerprints traces its origins back to ancient civilizations, with the recognition of patterned ridges on fingertips and palms predating the Christian era across multiple cultures and regions.

Fingerprints hold immense significance within the criminal justice system, offering a foolproof method for individual identification. This unique imprint is skin to an individual's seal and is even accepted as a signature for illiterate citizens in India. Its role as a potent defense against impersonation remains pivotal. Notably, fingerprints remain constant despite attempts by individuals to alter their identity, appearance, location, religion, or gender. Even in the case of deceased individuals, fingerprints are employed for unequivocal identification. This is particularly crucial when dealing with anonymous cadavers, putrefied remains, or mutilated bodies. In legal contexts, the evidentiary value of fingerprints ranks above other scientific evidence. In criminal trials, evidence must establish guilt beyond a reasonable doubt, and fingerprints offer scientific, physical, and documentary evidence that universally meets this high standard.

Criminals convicted for specific offenses have ten-digit fingerprint slips prepared, which include personal details and convictions. These slips are maintained permanently in fingerprint bureaus, aiding in establishing identity and proving criminal history. The process of obtaining fingerprints from criminals is outlined in Sections 3, 4, and 5 of the Identification of Prisoners Act and Section 73 of the Indian Evidence Act (Pandey, 2020; Stephen, 2023; *The Identification of Prisoners Act, 1920*, 2011)**.**

One of the most important contributions sciences has made in the investigation of crime and administration of justice is the development of chance prints left behind by criminals at the scene of crime and their identification. Despite all precautions, these prints are invariable left behind by criminals at the scene of crime, or on crime articles. As these prints come directly from the body of a person, their development and identification help to establish his physical presence at the scene of crime. Science of fingerprint identification is an exact science and

does not admit of any mistake or doubt. They thus serve as a valuable connecting link between the crime and the criminal **(Pawar, 2020)**.

Expert evidence on fingerprints is to assist in forming an opinion if a questioned print either on a document or from a crime scene could have been produced by the accused person whose specimen or admitted prints are available for comparison and identification. An expert witness is one who has devoted time and study and has thus acquired knowledge, skill and experience in a particular branch of learning and is thus especially skilled on the points, on which he is asked to state his opinion **(Langenburg, 2012)**. As for the fingerprints, the Government of India have constituted an All India Board of Examination of Fingerprint Experts and those who pass this examination are given expert certificate and declared accredited fingerprint experts. Fingerprint evidence needs no corroboration. But the evidence is not binding on the court. It cannot be laid down as a rule of law that it is unsafe to have conviction on the uncorroborated testimony of a finger print expert. The true rule seems to be one of caution. The court cannot delegate its authority to the expert, but has to satisfy itself as to the value to be given to the expert evidence in the same way as to the value given to any other evidence **(Cr. L.J. 1978 M.P. 1220)**. When the court permits the evidence of an expert to be brought on record, on a technical matter, it does not abdicate its function to judge for itself, whether the opinion of the expert is correct or not, on a matter of issue **(A.I.R. 1980, Allahabad 294)**. The infallibility of fingerprint identification is globally acknowledged, having withstood rigorous legal scrutiny for almost a century. This enduring profession remains a cornerstone in forensic science, maintaining its paramount status as a scientific tool in crime investigation and justice administration.

2.2. DEVELOPMENT OF FINGERPRINTS USING CONVENTIONAL METHODS

Powder method stands as the most ancient and uncomplicated technique to uncover latent fingermarks. Particles of powder adhere mechanically to the sweat or oil remnants within the fingermark residue, revealing the ridge patterns of fingermarks. In the end, the powder mixture adheres to the ridges but can simply blow off the grooves. A range of organic substances (like aniline dyes, soot, graphite, lamp-black, carbon black) and inorganic materials (such as colorants, ferric oxide, magnesium carbonate, lead oxide, lead acetate,

mercury, chalk, titanium dioxide, aluminium) are employed in powder formulations **(Goode & Morris, 1983; Mitchell, 1920)**.

The meshed metal powder compositions which are in use for a long time, have an advantage that they last longer on the shelf than normal powders do. Their drawback is that their metallic components cause people to experience adverse effects on the body. Some examples of metallic dusting compositions are grey powder with meshed aluminium and kaolin, silver powder with aluminium flake and pulverised quarts, and gold powder with bronze flake and pulverised quarts **(H. C. Lee, 1991)**.

Varieties like metal flake powders (aluminium, bronze), granular powders in black and white, magnetic powders, and fluorescent/luminescent powders like Mars red and coumarin-6 **(Thornton, 1978),** phosphorescent powder **(Menzel & Duff, 1979**) and others such as naphthol red B, rhodamine 6G and B, acridine yellow, Nile blue **(Menzel & Fox, 1980)** find extensive utilization **(Sodhi and Kaur 2001),** phosphorous powder **(L. Liu *et al*., 2009)** exhibits remarkable phosphorescence when exposed to UV (365 nm) light and has been effectively used for latent fingermark development across different surfaces. Occasionally, thermoplastic powders like photocopy toners **(Singla & Jasuja, 1992)** and anti-stokes powders (doped with lanthanides) have been explored by various researchers, yielding favourable outcomes in fingermark development **(Choi *et al*., 2008; Dilag *et al*., 2011).** Latent finger impressions were created using Silica Gel G on a variety of porous and non-porous surfaces, including glass, plastic, cardboard, CDs, wooden substrates, and paper. In comparison to other methods, this demonstrated superior results on non-porous surfaces and had better results on contrast surfaces **(Singh *et al*., 2013)**.

The SPR methods containing powders like black, white and fluorescent suspensions have powder, water and liquid detergent in it helps in the development of concealed finger impressions by interacting with the fatty acids of residue. An early instance involved creating a mixture of molybdenum disulfide in liquid detergent. Modifications in SPR formulation have included incorporating titanium dioxide **(Wade, 2002)** substituting synthetic liquid detergent with naturally extracted saponin **(Jasuja, Singh, and Sodhi 2007)**, and introducing fluorescent dyes like Rhodamine B, Rhodamine 6G, and cyano blue **(Jasuja, Singh, and Sodhi 2008)**.

The formulations consisting of basic zinc carbonate along with eosin (B and Y) as reagents with small particles were utilized to enhance hidden fingerprints on different nonporous surfaces. These treated surfaces were subjected to elevated temperatures (around 900°C) for a duration of 1 hour. Their findings revealed that the formulation containing eosin B exhibited superior fingerprint quality with more pronounced fluorescence when compared to the formulation utilizing eosin Y-based small particles **(Dhall *et al*., 2013)**.

Additionally, a nano powder-based SPR using ZnO-SiO_2 was devised and proven effective on wet, non-porous, dark-coloured surfaces **(Arshad *et al*., 2015).** This approach was also extended to various non-porous surfaces. On wet, dark surfaces, different white powders, such as talc, barium sulphate, titanium dioxide, zinc oxide, zinc carbonate, and basic zinc carbonate, were tested. Among these, a zinc carbonate-based powder suspension with a particle size of approximately 2μm exhibited optimal results in developing latent fingermarks on wet surfaces **(Frank & Almog, 1993)**.

On smooth, non-porous surfaces, iron oxide powder suspension was experimented with, excluding choline chloride. It was determined that choline chloride does not impact the development of latent fingermarks **(Haque *et al*., 1989; Pounds & Jones, 1981)**. The applicability of powder suspension was extended to various scenarios, including raw ivory **(Azoury *et al*., 2001)**, wet non-porous materials **(Polimeni *et al*., 2004)**, fire debris (Stow & McGurry, 2006), blood-stained fingermarks on dark backgrounds **(Au *et al*., 2011)**, and duct tape **(Bailey & Crane, 2011)** for latent fingermark development.

2.3. DEVELOPMENT OF FINGERPRINTS USING NANOPARTICLES

2.3.1. Conventional Nanoparticles

The Silicon Oxide Nanoparticles (SiO_2 NPs) possess unique properties that make them suitable for detecting and enhancing latent fingermarks. The reversed micro-emulsion method allows for the creation of SiO_2 NPs with a uniform size distribution. In this process, highly luminescent colorants can also be encapsulated within the NPs. Existing literature has demonstrated the efficacy of SiO_2-based NPs in latent fingermark detection. To synthesize the silicon oxide nanoparticles, micro-emulsion technique described by **(Moret *et al*., 2016)** was employed, utilizing Triton X-100 (TX-100), 1-hexanol, ammonium hydroxide (30%),

tetraethyl orthosilicate (TEOS), tris(2,20-bipyridyl) dichlororuthenium(II) hexahydrate (RuBpy), and sodium chloride (NaCl). The synthetic procedure involved combining 3.54 mL of TX-100, 15 mL of cyclohexane, and 3.6 mL of 1-hexanol in a round bottom flask, followed by the addition of 960 mL of RuBpy (16.6 mM), 200 mL of TEOS, and 120 mL of ammonium hydroxide (30 percent) **(Moret *et al.*, 2016)**. For surface functionalization, a mixture of 100 mL of TEOS and 100 mL of CES was added to the reaction mixture, which was continuously magnetically stirred for 24 hours. The mixture was then stirred for an additional 24 hours. To precipitate the NPs, the mini emulsion blend was transferred to a falcon centrifuge tube and 20 mL of acetone was added. The NPs were separated through centrifugation at 2500 RPM for 3 minutes, followed by removal of the acetone. Subsequently, the isolated NPs were treated with 15 mL of acetone. The NPs were then agitated in a falcon centrifuge tube using a vortex mixer and centrifuged again at 2500 RPM for 3 minutes until the acetone was drained. Finally, the RuBpy-doped CES-SiO_2 NPs (0.1 g) were collected and dispersed in 20 mL of RO/DI water. These collected nanoparticles were utilized for finger mark analysis obtained from various individuals. The finger-mark samples were divided into two halves and treated with SiO_2 NPs. Depending on the age of the finger marks (3 months old and 7 days old), were divided into different batches. A total of 288 finger-marks were included in the analysis. While variations were observed among the different donor groups, the assessment of the fingermark detection effectiveness was not affected, as all fingerprints were processed and evaluated in the relevant half. Significant differences were observed among the results collected from the three donors. However, improvements were noted in the detection efficiency for all three donors when using the modified detection parameters **(P. L. T. Lee *et al.*, 2022)**.

Monodisperse silica nanoparticles were used for the development of latent blood finger-marks. Stöber method was utilized to generate very consistent silica colloidal microspheres. The size of the silica particles could be regulated between 150 and 400 nm by modifying the formulation. In this experiment, a 250-mL flask containing 8.74 g of TEOS, and 180 mL of ethanol was stirred with a magnetic beater in a water bath that was kept at 35°C. Then, dropwise additions of 9.46 mL of deionized water and 10.0 mL of ammonia were made to the mixture, and the mixture was given an entire night to react. The resulting 240-nm MSNs were centrifuged to collect them, and any leftovers were cleaned up by rinsing them three times in ethanol. After that, the nanoparticles were either re-dispersed in ethanol for preservation or

dried in an oven. Spraying MSN suspension onto surfaces made of black, nonporous plastic allowed latent blood fingerprints to be seen. When irradiated with white or monochromatic light, this technique produced crisp and extremely visible images, demonstrating excellent efficacy in creating the fingermarks. Fine and smooth features were visible in the resulting fingermark ridges, and there was a clear contrast between the fingermarks and the background. Notably, the latent blood fingermarks did not need to be fixed before development because ethanol was present in the growing suspension. The MSNs' unique photonic crystal effect eliminates the need for fluorescent labels or dyes to visualise latent fingermarks. Moreover, the MSNs don't need to have their surfaces functionalized because they have a high affinity for the protein molecules found in blood fingermarks. This innate attraction also increases the detection window, permitting the retention of blood fingermarks for at least 30 days **(Meng *et al*., 2020)**.

Due to the affinity of metallic silver towards the organic elements in fingerprint residue, it has been used in the physical developer method as a reagent since 1970. This helps in latent fingerprints visualization on porous surfaces. The silver physical developer method is based on the oxidation-reduction reaction, where iron salt reduces the silver nitrate to metallic silver in an aqueous solution. The formation of silver nanoparticles takes place during the interaction of organic elements of fingerprint residue leads to the visualization of fingermark as a black silver image or dark grey on the surface. The development occurs due to the attraction of electrophoresis between the silver colloids (negatively charged) and fingerprint residues (positively charged). For porous surfaces, the silver physical developer method is appropriate as it visualized the prints on the moistened samples. The visibility of prints is not satisfactory. Therefore, before the treatment of prints with Ag-PD, it has been treated with gold nanoparticles stabilized with a citrate ion **(Prasad *et al*., 2020)**.

The hydrophobic carbon dots powder was synthesized with solid state emission for rapid visualization of latent fingerprints. The one-step thermal carbonization method was used for the preparation of N-doped carbon dots (NCDs) powder, which offered glowing NCDs powder in large quantities without the need for tedious purification and drying steps. The synthesis involved the thermal carbonization of o-phenylenediamine (OPD) and 2,6-pyridinedicarboxylic acid (2,6 PDC) at 180°C for 4 hours. The resulted NCDs powder was obtained without the need for tedious purification steps. The NCDs powder was insoluble in water and exhibits bright green fluorescence under 365 nm UV light. The optical properties

of the NCDs were studied. The NCDs powder was then used to develop latent fingerprints on various surfaces, providing sufficient contrast and presenting level 2 and level 3 ridge details for individual identification **(Bandi *et al*., 2020)**.

The Porous graphitic carbon nitride (pg-C_3N_4) was synthesized from bulk g-C_3N_4 (Bg-C_3N_4). The bulk g- C_3N_4 was prepared using poly-condensation of melamine as a precursor by thermal method. The pg- C_3N_4 was synthesized from Bg- C_3N_4 under ultrasonic treatment in a sulphuric acid medium and combined with commercial silica gel (Slg) to give a fluorescent Slg/pg- C_3N_4 powder. The fluorescent Slg/pg-C_3N_4 powder was used as a labelling agent for the latent fingerprints (LFP) development on various surfaces like aluminium foil, glass slides, aluminium sheets, aluminium rods, a compact disc (CD), iron discs, coins, a tea cup and spoon. The LFP were observed under ultraviolet radiation (365 nm). The Slg/pg- C_3N_4 powder was used to investigate the LFP images submerged in fresh water. The different fluorescent backgrounds of LFP images had been demonstrated using live cell microscopy with pg- C_3N_4 and Bg- C_3N_4. The fluorescent Slg/pg- C_3N_4 powder exhibited potential as a good labelling agent with excessive sensitivity, rapid detection and an eco-friendly nature. This fluorescent Slg/pg- C_3N_4 powder was also used to develop the LFP images under conditions that are likely to simulate real crime scenes to establish whether this material can be used in real forensic investigations. the detection under UV irradiation is still better than that under visible light so more modifications to the material need to be made for better detection under visible light (Prabakaran & Pillay, 2019).

A new magnetic nano powder was designed and prepared that can be used as a dusting agent for the development of latent fingerprints on different surfaces. The researchers aimed to investigate the influence of surface lipophilicity on the visualization of latent fingerprints and develop a lipophilic, selective, and efficient magnetic nano powder for this purpose. The researchers used Fe_3O_4@SiO_2 core-shell magnetic nanoparticles and modified them with trimethoxymethylsilane (TMMS) to obtain a lipophilic magnetic nano powder. They developed three types of magnetic nano powders - Fe_3O_4 MNPs, core–shell Fe_3O_4@SiO_2 MNPs, and lipophilic Fe_3O_4@SiO_2@Me MFNPs by co-precipitation and sol-gel method. The Fe_3O_4 MNPs were prepared through a co-precipitation method. Fe salts, ferrous chloride tetrahydrate ($FeCl_2 \cdot 4H_2O$) and ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$), were dissolved in deionized water under a nitrogen atmosphere. The pH of the solution was adjusted using aqueous NH_3, and the mixture was continuously stirred. The resulting magnetite precipitates

were washed and collected with an external magnet. Whereas, The Fe_3O_4@SiO_2 MNPs synthesized by dissolving $FeCl_2.4H_2O$ and $FeCl_3.6H_2O$ in deionized water and the pH adjusted to 9-11 using aqueous NH_3. The resulted magnetite precipitates were collected and washed. and coated with a silica shell to form Fe_3O_4@SiO_2 MNPs. The Fe_3O_4 black precipitate were dispersed in ethanol, and then aqueous NH_3 and tetraethyl orthosilicate (TEOS) were added. The resulted solution was stirred for 24 hours, and the Fe_3O_4@SiO_2 product was collected and washed. In case of Fe_3O_4@SiO_2 MNPs lipophilic, a synthetic strategy based on grafting trimethoxymethylsilane (TMMS) precursor was used. TMMS was added to dry toluene containing the Fe_3O_4@SiO_2 MNPs, and the mixture was stirred for 24 hours. The resulted lipophilic Fe_3O_4@SiO_2@Me MFNPs was washed and dried. Various analytical techniques such as transmission electron microscopy (TEM), energy-dispersive X-ray analysis (EDX), and vibrating sample magnetometer (VSM) were used to characterize the nanoparticles. The lipophilic Fe_3O_4@SiO_2@Me MFNPs showed superior performance in developing latent fingerprints compared to Fe_3O_4@SiO_2 and Fe_3O_4 MFNPs. The lipophilic MFNPs adhered more effectively to the greasy substances **(Mobaraki *et al*., 2019)**.

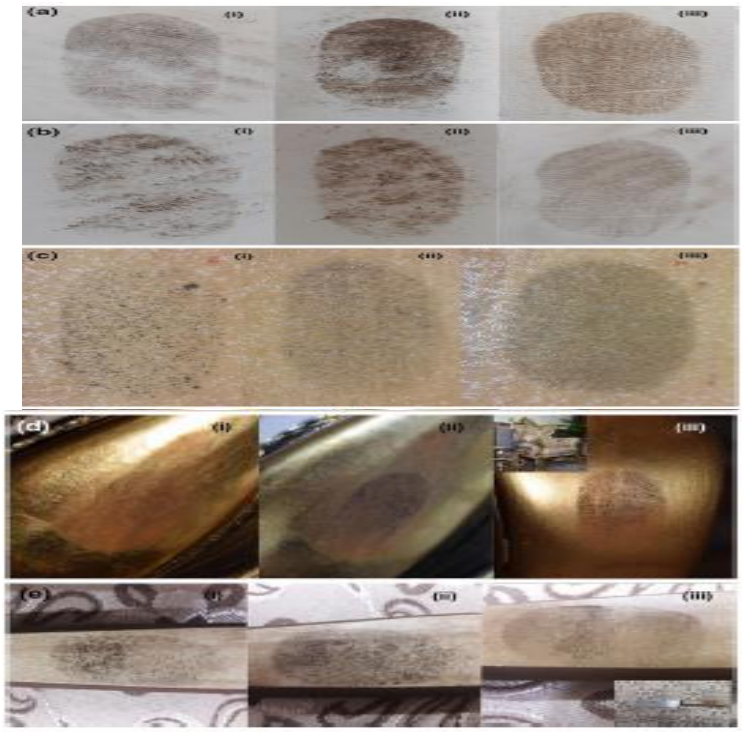


Figure 2.1 : Fingerprints developed with Fe_3O_4 (i), Fe3O4@ SiO_2 (ii) and Fe_3O_4@ SiO_2@Me (iii) MFNPs on various porous surfaces including a wall b a sheet of paper c a medium-density fiberboard (MDF) or engineered wood d a sofa and e a wooden handle of a knife. To see further LFPs photos taken from various individuals on the sheet of paper.

The study explored the use of Graphene carbon Dots (G-CDs) as a solution for developing latent fingerprints on high-density objects. The effectiveness of G-CDs in preserving and visualizing latent fingerprints over time was also investigated. The study examined the optimization of fingerprint development using G-CDs solution on various substrates, included sealed bags, glass coverslips, transparent tapes, and tin foil papers. The results showed that transparent tapes and tin foil papers yielded excellent latent fingerprint images with clear ridge lines, strong contrast, and detailed minutiae features. Whereas sealed bags and coverslips showed identifiable ridge lines and weaker fluorescence intensity. The impact of developing time, which refers to the time of substrates immersed in the G-CDs solution, was investigated in the study. The latent fingerprints on the tin foil paper were used as the sample. The acquired fingerprint images showed clear and coherent ridges, detailed minutiae features, and strong contrasts after 15 minutes of developing time. Prolonged developing time resulted in better fingerprint images and stronger fluorescence intensities. The optimal developing time for practical criminal investigation was found to be 30 minutes **(Zhao *et al.*, 2018).**

The precipitation technique has been employed to synthesize the zinc oxide and tin oxide nanoparticles, which were then characterized using X-ray diffraction, UV-Visible spectroscopy, and FTIR. The size of zinc oxide crystallite was 14.75 nm while tin oxide was found to be 90 nm in size. The results showed that zinc oxide nanoparticles were more effective in developing latent fingerprints on non-porous substrates such as glass, plastic, and glossy cardboard. The developed fingerprints were cleared depending upon the size and reflectivity of the nanoparticles. As compared to the tin oxide nanoparticles, zinc oxide nanoparticles gave clear and better-enhanced fingerprints on all the three surfaces **(Luthra & Kumar, 2018)**.

Figure 2.2: Fingerprint developed on Glass, plastic and Cardboard using Zinc Oxide nanoparticles

Researchers synthesized the calcium molybdate nanophosphor powders using the mixture of isopropyl alcohol (IPA) and de-ionized (DI) water as solvents. Three solutions were prepared: Solution-I contained calcium nitrate tetrahydrate dissolved in IPA, Solution-II contained sodium hydroxide dissolved in DI water, and Solution-III contained ammonium hepta-molybdate dissolved in DI water. The IPA slowed down the reaction and helped in the formation smaller particles. These solutions were mixed together, resulting in the formation of spherical-shaped calcium molybdate nanoparticles. The X-ray diffraction patterns confirmed the crystallization of the powders in a tetragonal phase. The luminescence spectra exhibited strong red and green emissions from the samples doped with Eu3+ and Tb3+ ions, respectively. The synthesised method allowed for the effective detection and enhancement of latent fingerprints on different surfaces, with high contrast and low background interference. The nanophosphors were applied to different substrates, such as slide glass, compact discs, and stainless-steel cups, resulted in clear and bright images of the latent fingerprints and it also showed the level II details in finger impressions. Whereas, level III details were not visible **(Bharat *et al*., 2017)**.

N doped carbon nanoparticles (CNPs) were synthesized using malic acid and ammonium oxalate as raw ingredients in a one-pot pyrolysis process. A powder that fluoresces in brilliant blue in the dried, strong condition was created by combining the carbon nanoparticles, which accounted for 1% of the mixture, with the distinctive starch. The exceptional advantages of the basic powder component's outstanding flowability and CNPs' astounding photoluminescence were combined with these materials. The point of convergence of this research was the use of nano-carbogenic powder as a unique UV fluorescent imprint for completely creating full fingerprints. To test the viability of fluorescent starch powder as fluorescence markings for the development of inert fingerprints on the glass, conventional staining agents such as iodine fume, commercially available cyanoacrylate stick fume, and TiO_2 powder were used as controls. The ability to produce latent fingerprints on the glass side with iodine fume, readily available cyanoacrylate stick fume, and TiO_2 was found to be insufficient. The fingerprints eroding borders made it challenging to distinguish them from the foundation. Due to their enhanced solid blue iridescence, fluorescent starch can be used as a successful powder for the development of inert fingerprints that have sharp edges, superior goal, and less foundation blockage. A series of identifications were made on various substrates to examine the affectability of the over four techniques. The affectability of iodine

fume, economically cyanoacrylate stick fume, and titanium oxide powder is lower than that of fluorescent starch powder. The CNP-based nanocomposites were used successfully as a novel fluorescent name for the creation of idle fingerprints on various substrates, exhibiting moderately all around created qualities for finger edge data and great differentiation for improved location. The CNP-based nanocomposites had stable compound properties and tuneable photoluminescent results. The study offers a brand-new method for creating complete inactive fingerprints using CNPs in the legal sciences **(Hongren Li *et al*., 2016).**

The dual visual senser based on polymer dots that helped in imaging of fingerprints were made by embedded ninhydrin into the Polymer dot matrix after scheming and synthesising two forms of near-infrared fluorescent polymers. The characterization of nanoparticles has been done by transmission electron microscope and dynamic light scattering. The fluorescence remained measured using fluorometer under 450 nm excitation and absorption spectra under UV-Visible spectrophotometer. The colorimetric and fluorescent dual-readout capabilities of the Polymer dot assay to spot dormant finger impressions on absorbent and non-absorbent exteriors were demonstrated. The chemical groups were also imbedded onto the surface of the nanoparticle to examine the process responsible in the growth of fingerprint. The assay has been used to image hidden fingerprints on cheques and note paper. This technique helped in detecting hidden fingerprints on all smooth surfaces with low background interference, high resolution, and contrast. It showed all the particulars of fingerprints from level one to three **(Y. H. Chen *et al*., 2016)**.

In another research, the ZnO-SiO_2 Nano powder synthesized by the conventional heating method using Zn $(CH_3COO)_2.2H_2O$, $Na_2SiO_3.5H_2O$, and NaOH and the characterization has been done by X-ray diffraction (XRD), energy dispersive X-ray (EDX) analysis, Fourier transform infrared spectroscopy (FTIR), scanning electron microscope (SEM), and transmission electron microscope (TEM). The particle size of ZnO-SiO_2 nano powder done by TEM was 32.9 nm. The development of latent fingerprints was done on different semi-porous and non-porous surfaces such as glass, calculator, board marker, laptop with the help of small particle reagent and powder dusting methods. SPR method has also been used on wet non-porous surfaces. They showed clear quality prints with second and third level details of ridges and as compared to the commercial powders they gave better visibility and just stick to the ridges, unlike commercial white powder which adhered to all over the surface **(Arshad *et al*., 2015)**.

An extremely fluorescent water-solvable cadmium-telluride quantum dots capped by mercapto-succinic acid basic solution was used to enhance the hidden fingerprints on numerous nonporous exteriors in 1–3 seconds. Mercapto-succinic acid cadmium-telluride quantum dots showed the higher sensitivity and image excellence when developing dormant fingerprints **(Cai *et al*., 2013)**.

An effective and easy technique was developed for the visualization of latent fingerprints processed by eccrine and sebaceous glands by using silver and gold nanoparticles produced by the electrochemical process. The electrodeposition approach has been used as it only occurs on the valleys between the ridges of fingerprints and the free conductive surface. This process enhanced the contrast and showed greater advantage as it is a simple, high resolution, non-hazardous and rapid method for the development of latent fingerprints on rough, smooth, clean and dirty conductive surfaces carried out in aqueous medium hence, suitable for wet samples. Different metal surfaces like stainless steel, platinum was taken and silver and gold were electrodeposited on the metal surface between the ridges of fingerprints. The result showed clear images of latent fingerprints on clean metal surfaces as compared to the dirty surface **(Qin *et al*., 2013)**.

In the advancement of the latent finger impressions technique, gold nanoparticles (AuNPs) played a noteworthy job due to their dormant nature, high selectivity and affectability, and qualities, which empower the capacity of the created fingerprints for a drawn-out timeframe **(Mohamed, 2011).** In the multi-metal deposition, the gold nanoparticles were used due to its significant properties which improve the permeability of the Latent fingerprints by two-advance sol-gel technique. The unique finger impression bearing surface was absorbed in the gold nanoparticles solution (balanced out in citrate ion medium) trailed by the expansion of silver physical developer **(Choi *et al*., 2008).** Using a UV-Vis spectrophotometer, characterization has been done. The gold nanoparticles bound to the residues of fingerprint and catalyse the precipitation of silver particles to metallic silver. Due to the electrostatic interaction between the positively charged finger impression residue and negatively charged gold nanoparticles, a silver picture of the dormant unique finger impression is acquired. However, the use of the MMD technique is constrained because it requires the item bearing the fingerprints to be washed in a fluid arrangement of the gold nanoparticles. Consequently, the technique isn't appropriate for building up the prints on surfaces, for example, dividers and floors or for any item too enormous to ever be absorbed a work area shower. This

technique is expensive.

2.3.2. Green synthesized nanoparticles

Graphene oxide was synthesized by the green reduction method using Emblica officinalis fruit extract as a reducing agent. Here, a green sol– gel method has been reported for the preparation of $ZnFe_2O_4$ and $ZnFe_2O_4$ -reduced graphene oxide (RGO) nanocomposite (NCO) using Aloe Vera extract as a capping agent. The NCO was found to be an alternate to traditional luminescent powder for a safe detection and qualitative improvement of latent fingerprints deposited onto different surfaces. The enhanced fingerprints display a well-resolved ridge flow and pattern configuration with an apparent resolution between bright ridge and dark substrates (level 1) and level 2 characteristics are also visible **(Amrutha *et al*., 2020).**

The use of a diluent matrix, the creation of core-shell nanostructures, the incorporation of heteroatom doping, the utilization of effects like resonance energy transfer and interactions, the use of molecular spacers, and other techniques have all been suggested to combat the tendency of graphene or other carbon based nano-materials in the solid state to self-quench **(H.-J. Wang *et al*., 2019; Q. Zhang *et al*., 2019).** Fernandes et al. were the first to demonstrate the use of carbon nanomaterials-based powders for fluorescent visualization of dormant finger impressions. They showed that the incorporation of 0.7 wt.% carbon nanomaterials into a silica matrix allowed a highly detailed and color-tunable visual display of dormant finger impressions on a glass slide as well as on a multicolor soft drink label **(Fernandes *et al*., 2015; Verhagen & Kelarakis, 2020)**.

The silica nanoparticles were synthesized using rice husk by thermochemical treatment which were then dyed with natural dyes. Fourier-transform infrared spectroscopy, Field emission scanning electron microscopy, X-ray diffraction analysis, and forensic alternate light source were used to record and characterise the powders' photoluminescence. By producing dormant fingerprints left on various multicoloured substrates, the efficacy of three fluorescent variants of silica nanoparticles powders and industrial fluorescent powder was studied. Rice husk was successfully used to make spherical fluorescent silica nanoparticles. Amorphous spherical silica nanoparticles with an average crystallite size of approximately 200 nm were discovered during characterization studies of coloured silica nanoparticles. Once heat was applied and

aged at room temperature, silica nanoparticles doped with curcumin pigment showed the best stability and greatest fluorescence. Electron microscopy and surface tests results on different surfaces showed that the dye doping method did not compromise the efficiency of the coloured silica nanoparticle. The results showed that it had strong photoluminescence, allowing for adequate contrast for fingerprint examination on problematic and challenging exteriors. The spherical mono-dispersed nanoparticles also improved the powder's transparency and selectivity **(Rajan *et al*., 2020).**

Some researchers worked on finding the new method for the synthesis of copper oxide nanoparticles. In this research, the CuO nanoparticles were coated with green tea extract to make them noncorrosive and environmentally sustainable. Copper sulphate ($CuSO_4.5H_2O$) and a commercial green tea were used to create copper oxide without the purification. It was combined with 50 mL of distilled water and 1 g of it in an Erlenmeyer flask. After 20 minutes of stirring at 700° to 800°C, a yellow-coloured solution was produced. The extracted solution is then kept in a refrigerator at 40 degrees Celsius. 20 ml of green tea extract was combined with 40 ML of $CuSO_4.5H_2O$ in an ultrasonic bath. The extract's original greenish-yellow hue was changed to brownish black. Centrifuging the integrated CuO arrangement at 10,000 rpm and removing the supernatant. The centrifugation-produced brownish-black crystals were taken out of the flask. Additionally, these crystals were ground into a powder. The latent prints were generated using a powder dusting technique on a variety of impermeable surfaces, including glass, white paper, margarine paper, and steel. Green tea functions as a reducing, covering, and balancing agent for CuO. Therefore, FE-SEM (Field Emission Scanning Electron Microscope) was employed for the characterisation, which revealed the size range of spherical nanoparticles between 500 and 900 nm. The findings were clearly visible with the unaided eye, and the crystals' dark hue defined the pores, ridges, and minute details. This technique for developing latent fingerprints using CuO and green teas is cost-effective, largely non-corrosive, and suitable for use at crime scenes **(Bhagat *et al*., 2019).**

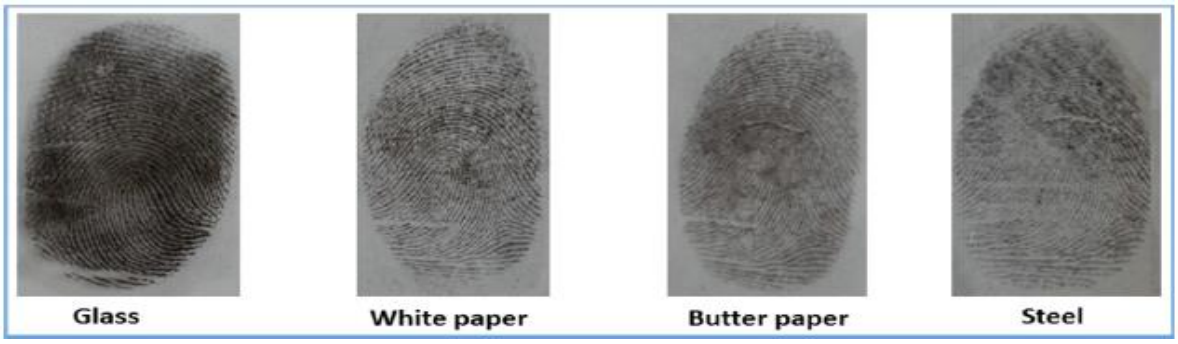


Figure 2.3: The developed finger impressions on different non-porous surfaces using CuO nanoparticles.

Mesoporous silica nanoparticles (MSN) were synthesized which have a particle size of 50 nm or less, for finding the concealed fingerprints. Tetraethyl orthosilicate (TEOS) was used as the silica source, triethylamine (TEA) served as a mineralizing agent, and water served as the solvent to create monodisperse MSNs **(Pan *et al.*, 2012)**. CTAC (2 g) and TEA (0.08 g) were dissolved sequentially in 20 mL of water at 95 °C with vigorous magnetic swirling during the synthesis process. 1.5 mL of TEOS was added dropwise after an hour, and the resulting liquid was agitated for an additional hour. To get rid of any remaining reactants, the products were centrifuged and repeatedly rinsed in ethanol. Following collection, the product was dried for 24 hours at 60°C in an oven. The CTAC surfactant was eliminated using two techniques: calcination and template extraction. For the calcination procedure, the dried product was heated up in a muffle furnace at a rate of 1°C/min commencing at ambient temperature for 6 hours at 550°C. The seized MSNs measured about 360 mg. The obtained MSNs were put into an ethanolic solution of hydrochloric acid [concentrated HCl (15 mL) in ethanol (100 mL)] and sonicated for two hours as part of the template extraction procedure. After that, the suspension was stirred for 24 hours at 70°C. To verify that all the surfactant was extracted, this extraction process was carried out again. The precipitates were then centrifuged, thoroughly cleaned with pure water, and subsequently disseminated in water or dried in a 60°C oven. The MSNs that were extracted measured about 385 mg. The mesopores of the MSNs were filled with molecules of the methylene blue (MB) dye to increase the contrast of the produced fingerprints. On various surfaces, two techniques—the powder and suspension approaches using MSNs and MSNs@MB—were tested, and both were successful in detecting latent fingerprints. In particular, the powder method outperformed the suspension methods in terms of contrast, selectivity, and resolution and was able to recognise the sweat

pores, a distinctive trait of the fingerprint's tertiary structure. To further boost MSNs' hydrophobicity, trimethylsilyl (TMS) groups were added to their surface. When compared to MSNs@MB, MSNs-TMS@MB performed worse in developing latent fingerprints **(M. Zhang *et al*., 2017)**.

In other study, the fluorescent silica nanoparticles were produced using Stöber method. The trimethoxy silane-modified fluorescent organic dye, 6 mg in weight and 0.17 mM in concentration, was dissolved in 45 mL of ethanol (EtOH). Then, consecutive additions of TEOS (1.08 mL, 0.097 M), water (1.6 mL), and ammonium hydroxide (1.6 mL, 0.23 M) were made to the solution. For 12 hours at room temperature, the mixture was agitated at a rate of 400 revolutions per minute (rpm). The resulting dispersion was then centrifuged for 20 minutes at 20,000 rpm to separate the precipitate, which was then re-dispersed in ethanol. More than three times were spent repeating this technique. The dispersion was then subjected to a further centrifugation at 3,800 rpm for 10 minutes, with the resultant supernatant being gathered for the following procedures. The leftover ethanol from the resulting solid pellet was removed to produce the PR254@SiO_2 powder. Hybrid organic/inorganic nanoparticles, which incorporate organic colours with amorphous silica, have been suggested as a potential remedy for the drawbacks. The matrix material is silica, which also offers biocompatibility and physicochemical stability to protect the contained dye from outside perturbations. A surface that is easily functionalized is another benefit of silica. It is possible to improve the interaction of silica nanoparticles with LFPs, which would increase the effectiveness of the detection process. For detecting LFPs, silica nanoparticles and organic ligands have been successfully used in prior investigations. Information on the connection between silica nanoparticle surface modification and the success of LFP development is still lacking, though **(Y. J. Kim *et al*., 2016).**

Amphiphilic silica nanoparticles have been produced using 4-(Chloromethyl) phenyl trichlorosilane as a surfactant and modified the silica spheres by in situ method by adding the tetraethyl orthosilicate with ethanol and deionized water. Hydrolysis and condensation were carried out with the aid of ammonia, which served as a catalyst. The amphiphilic silica nanoparticles synthesized by adding ammonia (25 percent), deionized water, and ethanol for 30 minutes at room temperature. Then, different doses of tetraethyl orthosilicate (0.5-gram, 1 gram, and 2 grams) were applied to create particles with various sizes. TDL-5-A used high-speed centrifugation to wash the solution five times after it had been agitated for eight hours.

Following that, the spherical monodisperse hydrophilic silicon dioxide particles were dried for twenty-four hours in a vacuum oven. Using this method, particles with average sizes of 250, 550, and 700 nm were produced. Afterwards, the spherical monodisperse hydrophilic silicon dioxide particles were altered by mixing one gramme of silica with one hundred millilitres of n-hexane. Using an ultrasonic oscillator, the silica particles were dispersed for thirty minutes. To create particles with the following SiO_2:4-(chloromethyl) phenyl trichlorosilane mass ratios of 250:1, 50:1, 15, and 1.5:1, 0.004 grams, 0.02 grams, 0.067 grams, and 0.67 grams of 4-(chloromethyl) phenyl trichlorosilane were added. The mixture was agitated for twelve hours before the nanoparticles were twice rinsed with high-speed centrifugation at a speed of 5,500 revolutions per minute and dried for twenty-four hours in a vacuum oven. The synthesized nanoparticles were used to detect the fresh and old Latent finger impressions. Due to their excellent hydrophilic and lipophilic characteristics, these particles are very selective and sensitive to amino acids. To improve the formulation of the nanoparticles, several particle sizes and SiO_2: 4-(chloromethyl) phenyl trichlorosilane mass ratios were examined. The development of latent prints performed best on silica spheres adjusted with a weight ratio of 50:1 and having a 700 nm diameter which helped in the latent fingerprint identification on smooth, nonporous objects **(Huang *et al*., 2015).**

The nanometers sized GNS, which have minimal toxicity, biocompatibility, and water solubility, are a subset of the nanomaterial class. Several applications, including bioimaging, drug delivery, gene transfer, metal ion detection, sensing, and nanothermometer, can make use of the photoluminescence property of graphene and other carbon nano materials **(Nugroho, 2022).** Many studies have shown that the carbon dots (CD) with liquid formulations display better visualization of hidden finger impressions. The colloidal stability of CD's dispersions in a variety of liquid media suggests that CD-based sprays give effective results **(J. Chen *et al*., 2017; Tang *et al*., 2019).** Although attempts have been made to increase the detection limit of latent fingerprints by using fluorescent nanomaterials such as graphene nano-sheets, quantum dots, carbon dots, and up-conversion nanoparticles, issues still persist due to their poor detection performance, difficult manufacturing process, photobleaching, and toxicity **(Y. J. Kim *et al*., 2016)(Y. Yang *et al*., 2019)**. There is a need to develop more efficient and cost-effective silica and graphene nanoparticles using easy methods.

2.4. OBJECTIVES

The main objectives of the present work are:

1. Green Synthesis and characterization of nanoparticles.
2. Development of latent fingerprints on different surfaces (porous and non-porous).
3. Toxicological studies of the synthesized nanoparticles.

CHAPTER-3

SYNTHESIS, CHARACTERIZATION, TOXICITY ASSESSMENT AND LATENT FINGERPRINTS OF MESOPOROUS SILICA NANOPARTICLES

3. SYNTHESIS, CHARACTERIZATION, TOXICITY ASSESSMENT AND LATENT FINGERPRINTS OF MESOPOROUS SILICA NANOPARTICLES

3.1. MESOPOROUS SILICA NANOPARTICLES (MSNPS)

The structural components of fingerprints contain both hydrophilic and hydrophobic characteristics as they encompass water, proteins, fatty acids, lipids, and inorganic salts. The mesoporous silica nanoparticles (MSNPs) have great potential to be utilized in developing the latent fingerprints due to their properties like optical transparency, tiny particle size, large surface area, high fluorescence, robust photo-stability, outstanding biocompatibility, low toxicity, and high surface absorbency. The components of fingerprint impressions which stays on the surface needs the better adsorption property material which can help in the enhanced latent finger impression development. The adsorption of silica nanoparticles can be improved by frequently increasing the surface functionalization with hydrophobic and/or hydrophilic groups. Following that, they offer fingerprint visualization using fluorescence markers. The surface controllability of MSNPs is another appealing quality of them as compared to other semiconductor materials. The emission of fluorescence is significantly impacted by changes in surface conditions. On numerous non-porous surfaces, including glass, plastic, and stainless steel, the capacity to discern fingerprints has been demonstrated utilizing the silica nanoparticles (ÇETLİ *et al*., 2022; Leśniewski, 2016; Meng *et al*., 2020).

3.1.1. Chemicals and Reagents

The chemicals used for the synthesis of mesoporous silica nanoparticles were Cetyltrimethylammonium bromide (CTAB), ammonium hydroxide, and tetraethyl orthosilicate (TEOS), silica, fumed (SiO_2) (MW 60.08, 0.2–0.3µm), and Whatman® Grade 1 filter paper was purchased from the Sigma-Aldrich (St. Louis, MO, USA). Hydrochloric acid (HCl), methanol, ethyl acetate, mercuric chloride, and ethanol were purchased from the Merck (Mumbai, India). All the chemicals used in this research work were of Analytical Grade.

3.1.2. Sample collection of latent fingerprints

- **Participants:**

For the purposes of the study participants who were healthy and having normal hands of age group 18-35 were included and those with any kind of injury on fingertips that leads to change in the pattern like lacerations, leprosy, scars, burnt fingers etc. were excluded. Each participant was instructed to wash the hands with soap and water. After which the fingers were placed on various surfaces (Both porous and non-porous surfaces). The volunteers were asked to touch or hold the surface (with the similar force as they hold other things in routine) for 10 - 15 seconds. Each participant's full and incomplete fingerprints were obtained on these surfaces. Informed written consent was taken prior to taking the fingerprints with proper procedure explained to subjects. The collected latent finger-marks on different surfaces were kept untouched for 24 hours before being processed and considered as fresh finger-marks.

- **Surfaces**

Non-porous: Glass mug, Steel Mug, Plastic Container, Glass Slide, Plastic Lid, Mobile Cover, transparent poly bag

Semi-porous: Coloured-visiting card, Wooden Keychain, Wall.

Porous: office A4 sheet papers, printed papers, cardboard.

In the current research work different surfaces were used for the MSNPs as well as GNSs nanoparticles application. The surfaces were taken as per the need of the work. Few of the surfaces were cut into short pieces to get the sufficient area to impress a fingerprint.

Table 3.1: Different surfaces used for taking fingerprints

Porous Surfaces	 Colored paper Plain paper
Non-Porous Surfaces	  

Semi-porous surface	 Wooden Key

3.1.3. Development of latent fingerprint using nanoparticles

Powder: The nano powder has been applied on the surface using a feather brush and camel hairbrush. These brushes are best suited on the various porous and non-porous surfaces for the latent fingerprints development. The light strokes were made to develop the prints on the surface by camel hairbrush.

3.1.3.1. Synthesis of nanoparticles

Bottom-up synthesis has been utilised to create mesoporous silica nanoparticles (MSNPs). The MSNPs were synthesized using the Sol-gel process. The idea underlying this procedure is that components should go from the solution or sol phase into the gel phase. Through a polycondensation reaction in the solution phase, an oxide network is formed. Sol-gel method that has been used for many years to generate metal oxide and ceramic powders with a high degree of homogeneity and purity. This technique works well for producing inorganic-organic hybrid materials as well as oxide nanoparticles.

Silicon tetraethyl orthosilicate, commonly referred to as TEOS (Si $(OC_2H_5)_4$), is the prevailing alkoxide. It experiences partial or complete hydrolysis, resulting in the formation of silanol.

$$Si(OR)_4 + H_2O \rightarrow Si(OR)_3(OH) + ROH \quad (3.1)$$

The hydrolysis of silicon alkoxides occurs at a relatively sluggish rate. However, introducing acid or base catalysts accelerates the transformation of metal precursor molecules into Tri alkoxyl silanol (Si $(OR)_3(OH)$).

The extent of hydrolysis, which entails the conversion of all alkoxides OR groups into OH, depends on the quantity of water and catalyst present.

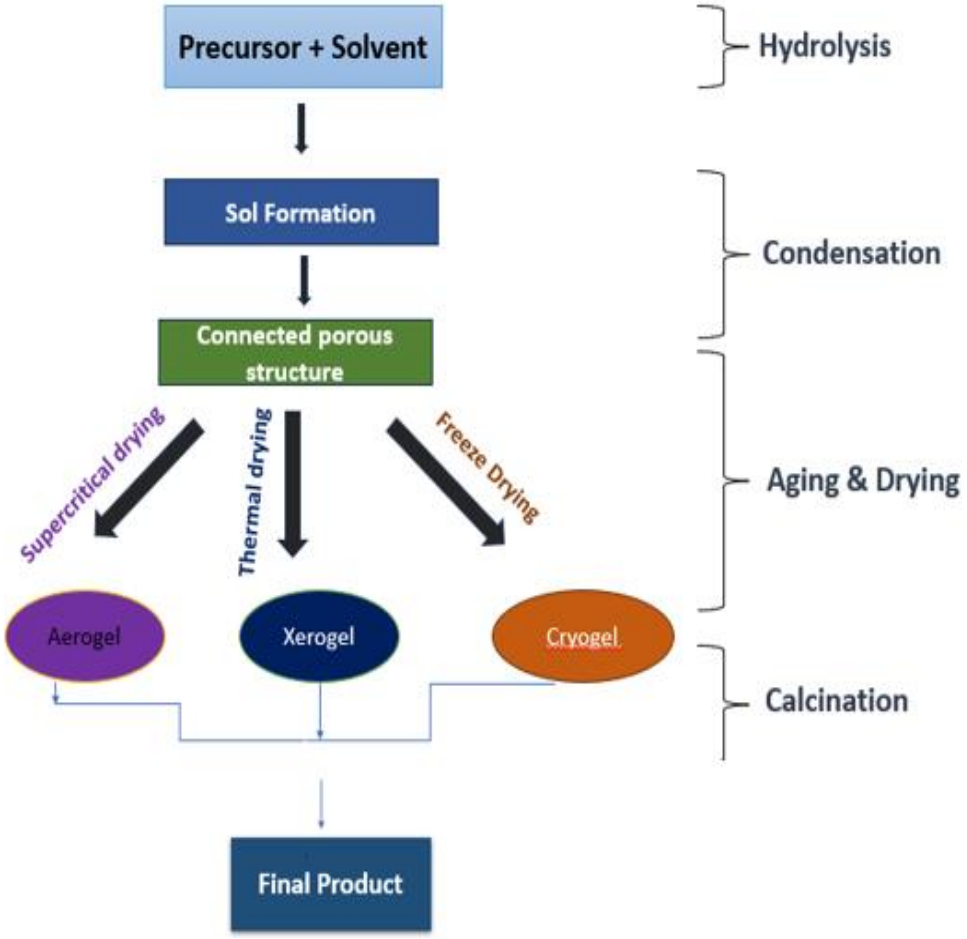


Figure 3.1: Steps involved in Sol-gel process.

Further condensation yields cluster species siloxane (Si-O-Si).

$$(OR)_3Si - OH \; + \; HO - Si(OR)_3 \quad \rightarrow \quad (OR)_3Si - O - Si(OR)_3 \; + \; H_2O \quad (3.2)$$

For the synthesis of MSNPs, 0.055 M n-hexadecyl-trimethylammonium bromide (CTAB) aqueous solution was prepared in 10 mL Milli-Q water under vigorous stirring for 30 min. After that, the stirred solution was heated at 60°C for 15 minutes. Then the heated mixture was cooled at room temperature and a solvent mixture containing 5 mL of methanol, 95 mL of MilliQ water, 3 mL of ammonium hydroxide (NH_4OH), and 20 mL of ethyl acetate ($CH_3COOC_2H_5$) were added into it. The mixture was kept under stirring condition and then 300 µL of tetraethyl orthosilicate (TEOS) was added to the reaction solution. The resulting

solution was stirred for 12 hours. This leads to the synthesis of MSNPs. The synthesized MSNPs were then washed using excess ethanol. The prepared MSNPs were stored in 40 mL ethanol until further use. For the extraction of CTAB from the solution, the pH was adjusted till 1.6 and stirring was continued for 3 hours at 60 °C. Then the product was washed with ethanol three times and then dispersed in 20 mL of ethanol and stored at room temperature for further characterization. The aliquots were sealed tightly (Cha *et al*., 2018; J. Kim *et al*., 2006; Kwon *et al*., 2017).

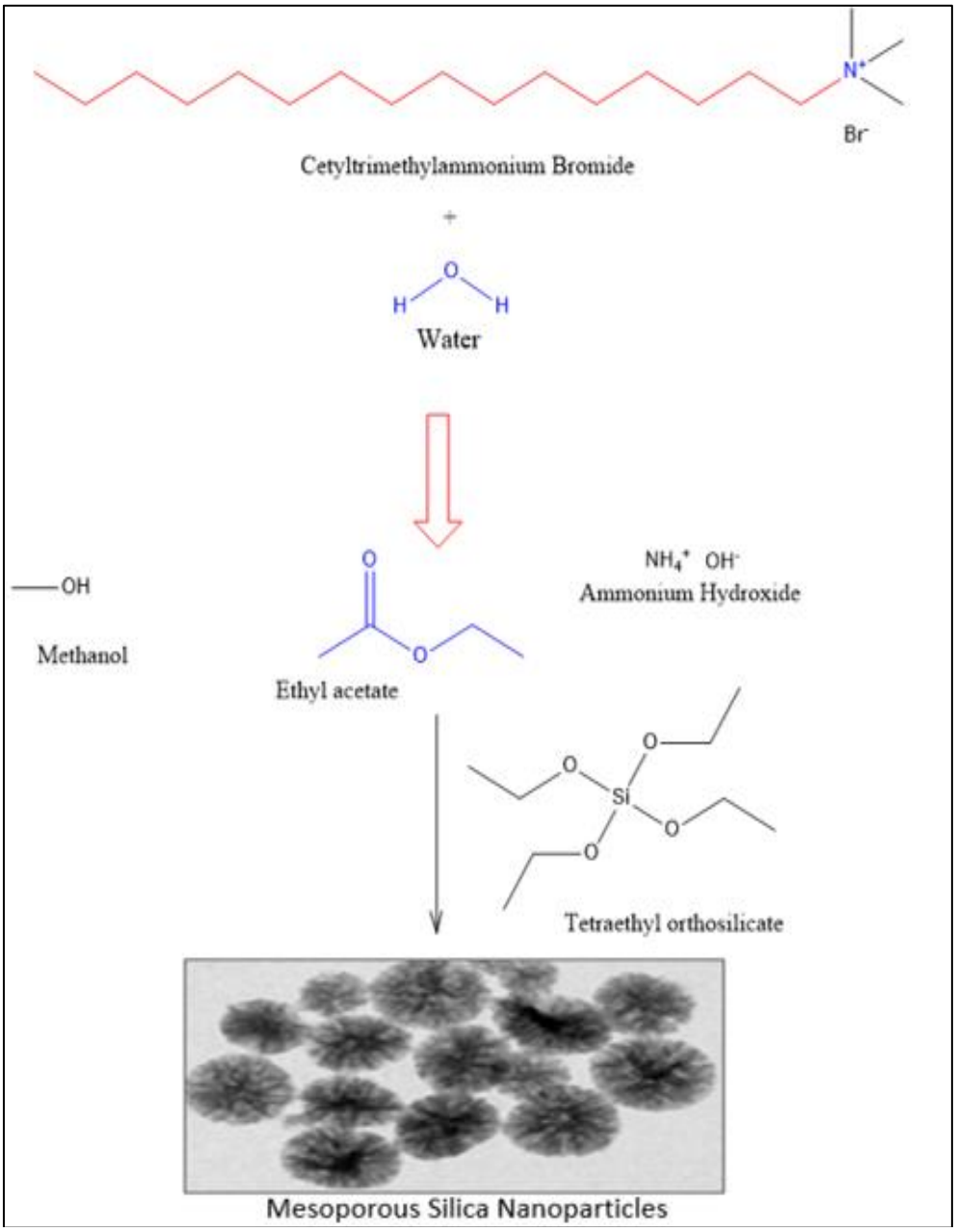


Figure 3.2: Schematic representation of synthesis of MSNPs.

3.1.3.2. Characterization of synthesized nanoparticles

The synthesized product was characterized using FTIR spectrophotometer, Scanning electron microscopy, BET, BJH, EDX, and TEM.

3.1.3.2.1. Morphological characterization

Scanning electron microscope (SEM)

Scanning electron microscope was used to observe the morphological characterization of the synthesized MSNPs. SEM is a helpful technique for the characterization of materials because it exposes the sample to a high-energy electron beam, which provides information about a materials topography, morphology, composition, chemistry, grain orientation, crystallographic information, etc. Morphology describes the size and shape of an object, whereas topography describes the surface characteristics, such as its texture, smoothness, or roughness (Venkateshaiah *et al*., 2020).

For SEM, dried samples were coated in a sample holder and coated with gold-palladium sputtering followed by SEM analysis at different magnifications. A focused beam of electrons is created by producing them at the top of the column, accelerating them as they descend, and passing them through a number of lenses and apertures. This focused beam of electrons then impacts the sample's surface. The sample was put on a stage in the chamber region. Scan coils located above the objective lens are in charge of adjusting the position of the electron beam on the sample. These coils enable the beam to scan across the sample surface. Several signals are generated as a result of the interaction between the electron and the sample. The right detectors are then used to find these signals. A high-energy electron beam is used to scan the sample in the scanning electron microscope (SEM) to create images. Secondary electrons, backscattered electrons, and distinctive X-rays are created as a result of the electrons interactions with the material. The detectors gather these signals to create the visuals that are then shown on the computer screen. Depending on the accelerating voltage and the density of the sample, the electron beam penetrates the sample when it strikes the surface to a depth of a few microns. This interaction inside the sample results in the production of a variety of signals, including secondary electrons and X-rays (Akhtar *et al*., 2018; Subramanian *et al*., 2018).

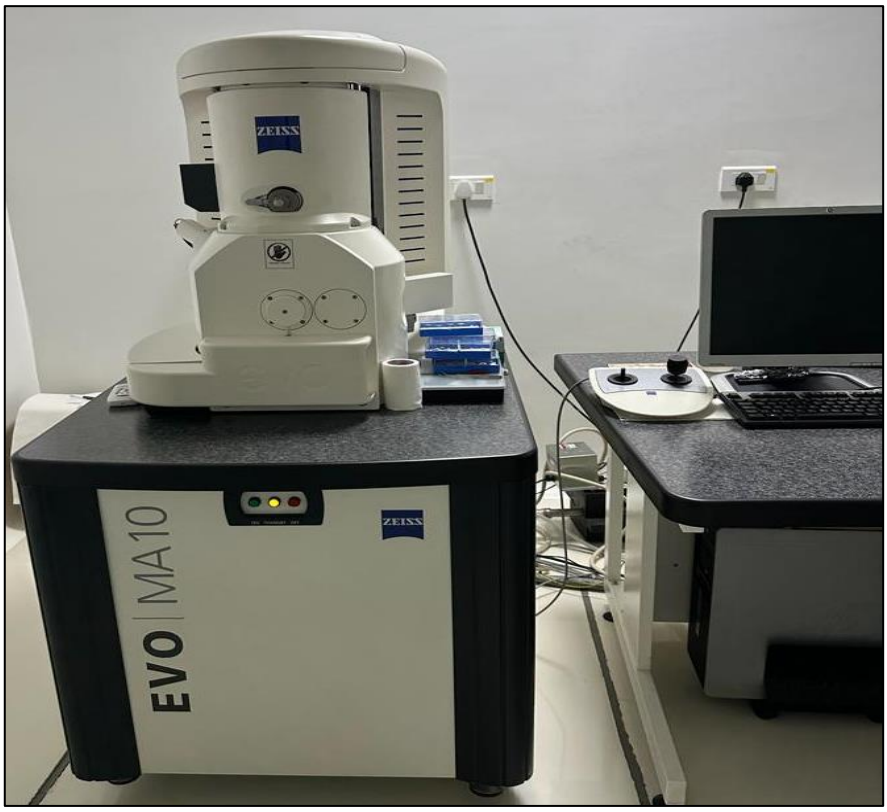


Figure 3.3: ZEISS EVO MA10 SEM Instrument

Transmission Electron Microscope (TEM)

TEM samples were prepared in ethanol and sonicated for 10 min followed by dropping on copper grid and dried under hygroscopic chamber at room temperature. TEM is a technology that transmits an electron beam through a thin specimen while the electron interacts with the material. High lateral spatial resolution and the TEMs capacity to produce both the picture and the samples diffraction are two of its most significant qualities. Using this method, it is possible to fully analyse the materials morphology, crystal structure, atomic structure, microanalysis (chemical composition, bonding), electronic structure, and coordination number.

3.1.3.2.2. Structural characterization

Fourier-Transform Infrared spectroscopy (FTIR)

The synthesized nanoparticles were exposed to infrared light from the FTIR instrument using a Thermo scientific Nicolet iS20 FTIR spectrometer at room temperature in the spectral ranges of 4000 –400 cm^{-1}, some of which is absorbed and some of which passes through . The sample molecules transform the absorbed radiation into rotational and/or vibrational energy. The resulting signal, which appears as a spectrum at the detector ranged 4000 –400 cm^{-1}, represents the sample's molecular fingerprint. As each of the molecule or chemical structure will provide a distinct spectral fingerprint, radiation from the source causes the sample to go through the interferometer and end up at the detector. The signal is then amplified and transformed into a digital signal by an analog-to-digital converter and an amplifier, respectively (Petit & Madejova, 2013). The signal is eventually sent to a computer, where the Fourier transform is run.

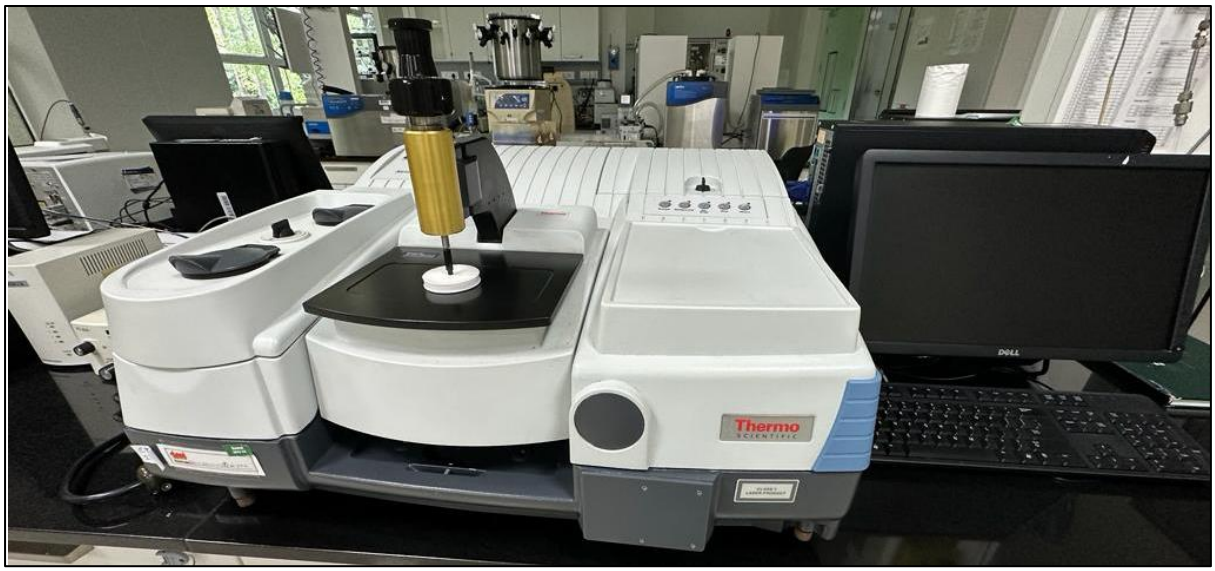


Figure 3.4: Nicolet iS20 FTIR Instrument

Barrett–Joyner–Halenda (BJH)

The Barrett–Joyner–Halenda (BJH) method was used for the measurement of pore size and pore volume using an Autosorb automated gas desorption analyser. It is based on the analysis of the desorption branch of an adsorption isotherm and provides information about the size and volume of pores within the material (Terzyk *et al*., 2012). The BJH method assumes cylindrical pores and utilizes the phenomenon of capillary condensation. It approximates the

shape and size distribution of the pores based on the adsorption and desorption behaviour of the gas molecules within the pores. The working principle of the BJH method involves the following steps:

Adsorption Isotherm Measurement: The material of interest is subjected to gas adsorption, typically using nitrogen, at various relative pressures (P/P^o) where P stand for Pressure and P^o for saturation pressure of the pure adsorptive at the operational temperature. The adsorption isotherm, which represents the amount of gas adsorbed as a function of relative pressure, is recorded (Kong & Liu, 2014).

Calculation of Pore Size Distribution: It focused on the desorption branch of the adsorption isotherm, where gas molecules start to desorb from the surface and pores. By applying the Kelvin equation, which relates the equilibrium pressure at which desorption occurs to the pore size, the pore size distribution can be calculated.

$$In\left(\frac{p}{p^0}\right) = -2\gamma V_m/RT(r_p - t_c) \qquad (3.3)$$

Where γ stands for the surface tension of liquid nitrogen, V_m the monolayer volume, R the universal gas constant, T statistical thickness, r_p for pore radius, t_c for the thickness of adsorbed multilayer film

Pore Volume Calculation: The pore volume is determined by subtracting the amount of adsorbed gas at a specific relative pressure from the monolayer capacity. The monolayer capacity is estimated using the BET method (Bardestani *et al*., 2019).

BJH Plot Construction: It shows the cumulative pore volume against the pore diameter, where the pore diameter is calculated from the Kelvin equation. The slope of the BJH plot provides information about the pore size distribution, while the area under the curve represents the total pore volume (Ojeda *et al*., 2003).

Brunauer–Emmett–Teller (BET)

Brunauer–Emmett–Teller (BET) measurements were done to measure the surface area of the synthesized Si NPs. It is based on the adsorption of gas molecules onto the surface of the material and the analysis of the resulting adsorption isotherm (Bardestani *et al*., 2019). The BET method allows for the calculation of the specific surface area by assuming a monolayer

adsorption onto the surface. The working principle of the BET method involves the following steps:

Adsorption Isotherm Measurement: The material under investigation is exposed to a gas, typically nitrogen, at various relative pressures (P/P_0). The gas molecules adsorb onto the surface of the material, forming a layer of adsorbate.

Monolayer Adsorption: At low relative pressures, the adsorption occurs in a monolayer fashion. The gas molecules occupy specific adsorption sites on the surface, forming a complete monolayer. This monolayer coverage corresponds to the maximum adsorption capacity of the material.

Multilayer Adsorption: As the relative pressure increases, additional gas molecules begin to adsorb onto the previously formed monolayer. This results in the formation of multilayers of gas molecules on the surface.

BET Plot Construction: The BET method involves constructing a plot known as the BET plot. It involves plotting the quantity of-

$$(P/P^0)(V/Vm)\ against\ P/P^0 \qquad (3.4)$$

where V is the volume of gas adsorbed and Vm is the monolayer volume. The plot shows a linear region at intermediate relative pressures.

BET Specific Surface Area Calculation: The slope of the linear region in the BET plot is used to calculate the BET specific surface area. The formula for the specific surface area (S) is given by

$$S = (6 / C) \times (Vm / m) \qquad (3.5)$$

where C is the constant related to the gas used, Vm is the monolayer volume, and m is the mass of the sample (Sinha *et al*., 2019).

Energy dispersive X-ray

The morphology of the synthesized MSNPs was examined using a JEOL 2100F transmission electron microscope (TEM) at 200 kV connected to an energy dispersive (EDX). As EDX helps in determining the elemental composition of a material. This work on the principle of

X-ray fluorescence. When a high-energy electron beam interacts with a material, it causes the atoms to undergo various interactions, including ionization and excitation. As a result, inner-shell electrons are ejected, creating vacancies. These vacancies are filled by outer-shell electrons, and during this process, characteristic X-rays are emitted (Cox, 1985; Shindo *et al*., 2002). The energy of these emitted X-rays is specific to each element, allowing for their identification and quantification.

Figure 3.5: Elemental analyser Instrument

3.1.3.3. Assessment of post-synthesis stability of MSNPs

Stability of these MSNPs in terms of aggregation and nanoparticle size, prior to soil and foliar application, was assessed using quantitative non-plasmonic characterization technique (DLS-Dynamic Light Scattering) at different time intervals (0-72 hours).

Figure 3.6: Zetasizer Instrument

3.1.3.4. Toxicity level of the synthesized MSNPs via cell viability analysis

To check the cytotoxicity of the synthesized mesoporous silica nanoparticles, lung epithelial cells of human origin (beas-2) were purchased from the American Type Cell Culture Collection Centre (ATCC). The purchased cells were maintained in RPMI cell culture medium accompanied with foetal calf serum and penicillin−streptomycin (1%), under the carbon dioxide atmosphere at 37 °C. The growth of cells in the culture medium has been observed and was confirmed after every second day. The culture medium was keep refreshing as needed.

The biocompatible nature of the synthesized highly porous MSNPs was measured *via* 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenylshytetrazolium bromide (MTT) assay. Two days prior to assay, cells (Hela) were cultured at the density of 5×10^4 cells/well followed by incubation for 24 hours until confluency of 80%, after which the cells were treated with different concentrations of MSNPs (5, 10, 15 and 20 μg mL^{-1}) followed by incubation for 18−24 hours at 37 °C. Cells were then treated with 5 mg mL^{-1} MTT reagent to achieve blue crystals that were dissolved in dimethyl sulfoxide and absorbance was then measured at 540 nm. Results were calculated based on initial and final absorbance measurements taken at 490 and 680 nm, respectively. The cells were also checked for their microscopic morphological alterations after the treatments.

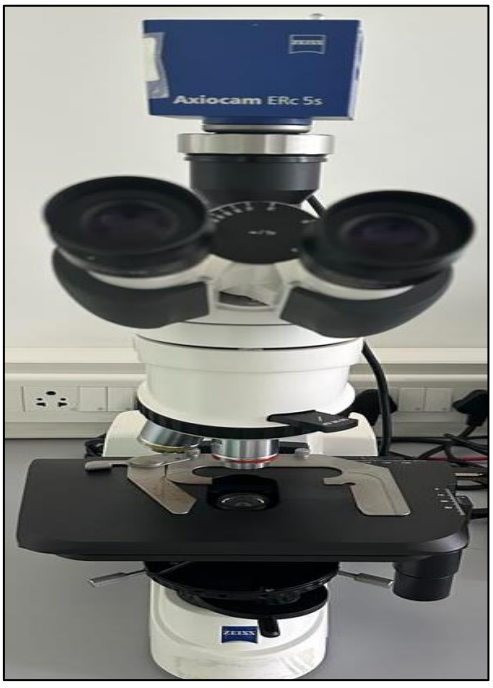


Figure 3.7: Compound Binocular Microscope

3.1.3.5. Application of MSNPs for detection of fingerprints

The synthesized MSNPs were tested for their ability for detecting fingerprints on different types of surfaces (porous, semi-porous, and non-porous). By using a feather brush, nano-powder of MSNPs which is white in colour was dispersed to the multiple surfaces as it contrasted well with both coloured and dark surfaces containing latent finger impressions. The applied powder is supposed to react with the components present in the finger impressions which is left on the surface because of the sweat and oil secreted by sebaceous, eccrine, and apocrine glands.

3.2. RESULTS AND DISCUSSION

3.2.1. Synthesis of Synthesized MSNPs

The MSNPs were prepared using ethyl acetate which is referred to as a pore expansion agent. In the context of nanoparticle synthesis, pore expansion refers to the creation or enlargement of empty spaces (pores) within the structure of the nanoparticles. It was added in the presence of CTAB which interacts with both water and oil-based substances. CTAB acts as a stabilizing secondary surfactant for the transfer of the nanocrystals to the aqueous phase but also the organic template for the formation of mesoporous silica spheres. It assists in guiding the growth of the mesoporous structure within the silica nanoparticles by a silica sol-gel process.

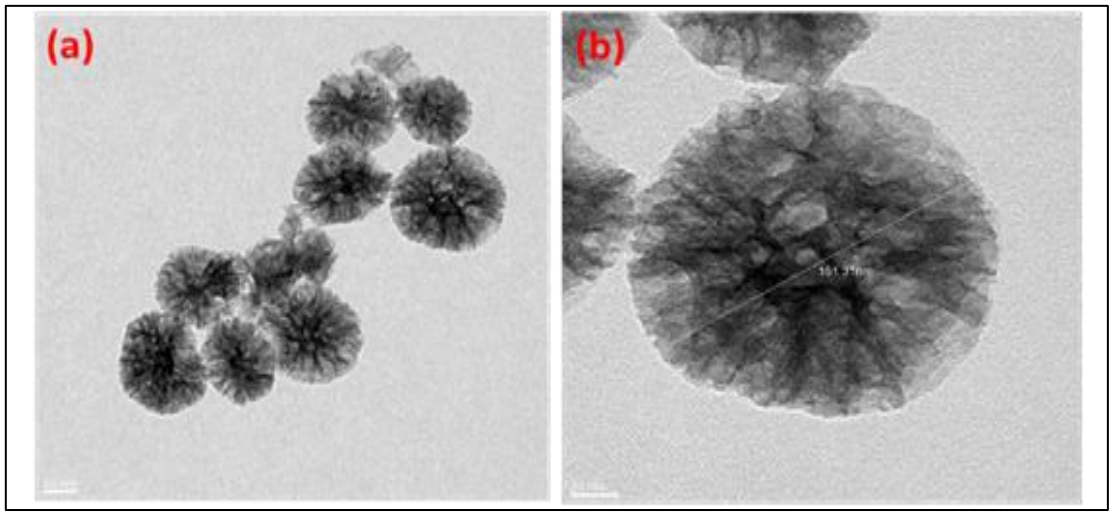


Figure 3.8 : (a-b) TEM morphological characterization of synthesized MSNPs

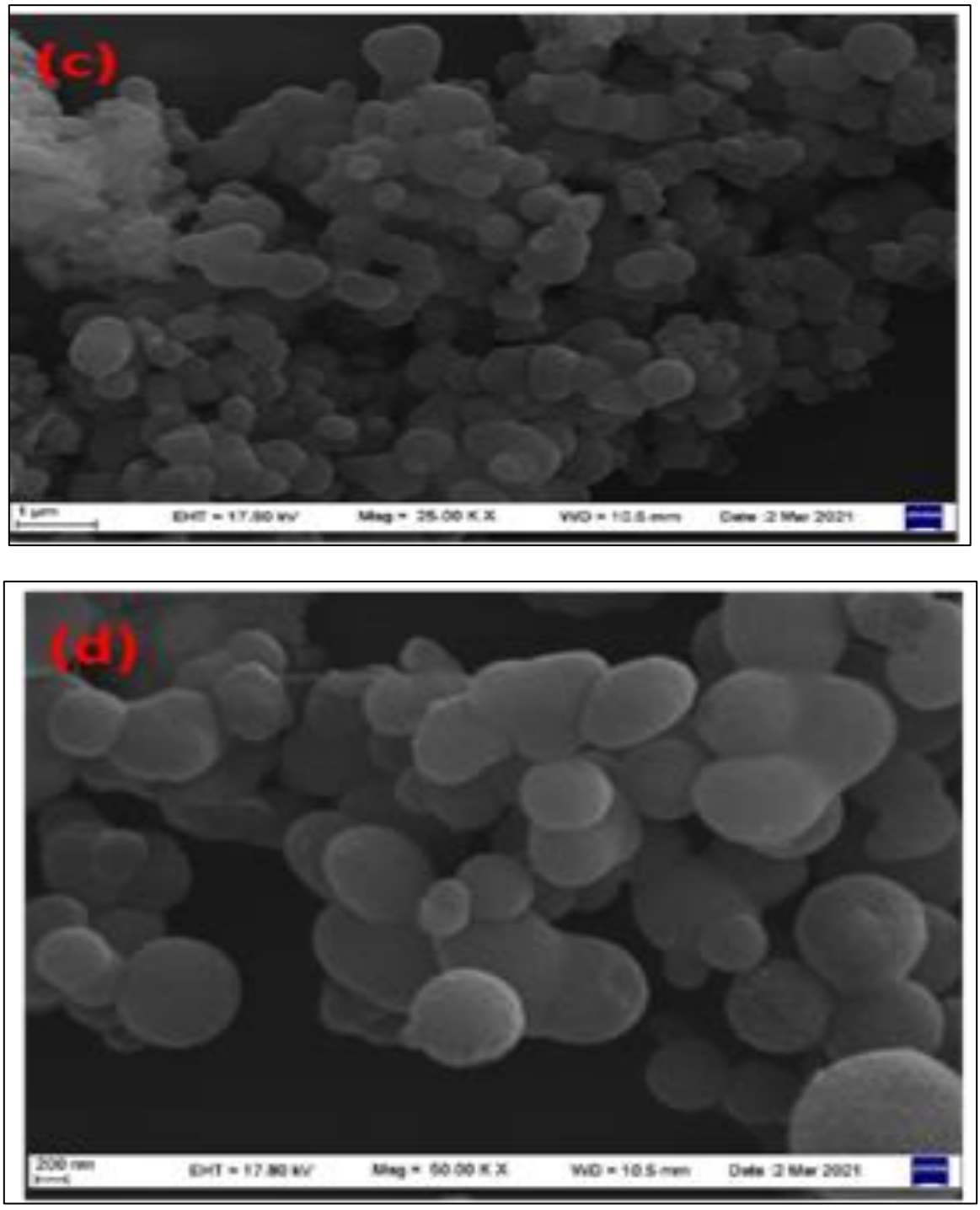


Figure 3.9: (c-d) SEM morphological characterization of Synthesized MSNPs

3.2.2. Characterization of synthesized MSNPs

The Characterization of the synthesized MSNPs using TEM (Figures 3.8a and 3.8b) and SEM showed the flower like structure with big pore size having deep furrow like mesopores having

size of 10.5nm (Figure 3.9c and 3.9d). These deep furrow mesopores allows the higher deposition of any foreign materials and help easily in finger print detections.

3.2.2.1. Fourier-Transform Infrared spectroscopy

FTIR was used to extensively examine the functional groups in the synthesized mesoporous silica nanoparticles (MSNPs) in the spectrum region of 4000–400 cm^{-1}. Specific absorption bands with distinctive wavenumbers were detected by FT-IR spectroscopy in the MSNPs (Figure 3.10), demonstrating the presence of silicate. Each of these bands, which were found at the wavelengths of 784.71 cm^{-1}, 1057.45 cm^{-1}, 1609.33 cm^{-1}, and 3308.95 cm^{-1}, corresponds to a different vibrational mode connected to silicate bonds. The siloxane bond, a crucial component of silica structures, was evident in the absorption band at 784.71 cm^{1}. Another indication that silicate is present in the MSNPs is the band at 1057.45 cm-^{1}, which was attributed to Si-O-Si bending vibrations. The hydroxyl groups on the surface of the nanoparticles were confirmed by the association of the absorption band at 1609.33 cm^{1} with silanol (Si-OH) symmetric stretching vibrations. These hydroxyl groups are essential for the reactivity and functionality of the MSNPs. Furthermore, the band observed at 3308.95 cm^{-1} was assigned to silanol (Si-OH) bending vibrations, which further confirmed the existence of hydroxyl groups in the synthesized nanoparticles. These results align with previous studies by (Huang *et al*., 2015), (Sevimli and Yilmaz 2012), and (Wardhani *et al*., 2017), which have also reported similar characteristic absorption bands in the FT-IR spectra of silica-based nanoparticles. The FT-IR spectroscopy analysis provided valuable insights into the composition and functional groups present in the synthesized MSNPs, confirming the presence of silica and its characteristic bonding patterns. These findings contribute to a comprehensive understanding of the structural and chemical properties of the nanoparticles.

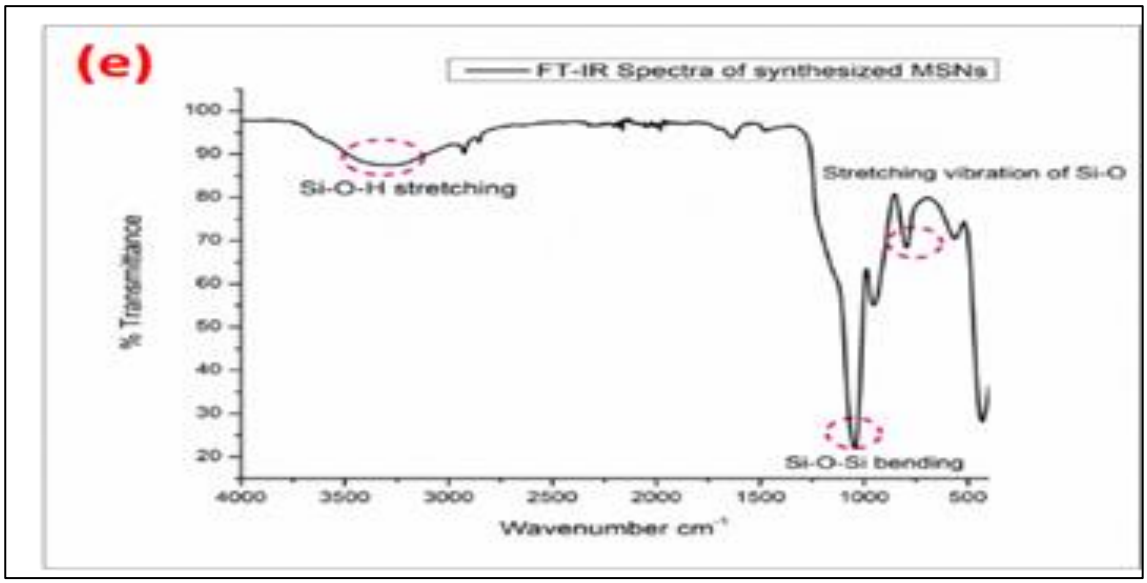


Figure 3.10: FTIR measurements of synthesized MSNPs

3.2.2.2. Brunauer-Emmett-Teller (BET)

The pore size and volume of the MSNPs were investigated using N_2 sorption analysis. It is a widely used technique to characterize the porous structure of materials. The results revealed that the MSNPs possessed bimodal pores, meaning that they had two distinct pore size distributions. The peaks in the pore size distribution were observed at approximately 7.2 nm, indicating the presence of pores with a significant size around this value. The value of 941.88 m^2 g^{-1} was reported for the BET surface area, which measures the specific surface area accessible for adsorption. The pore volume of the synthesized MSNPs was determined to be 1.30 cm^3 g^{-1}. The relatively high pore volume in the MSNPs suggests that they have a significant storage capacity for various substances, making them suitable for applications involving the loading and controlled release of drugs or other molecules. The combination of a bimodal pore structure with a large BET surface area and substantial pore volume makes these MSNPs promising candidates for a wide range of applications in nanotechnology and material science. These characteristics facilitate efficient encapsulation and delivery of active compounds, while also allowing for interactions with guest molecules through adsorption processes.

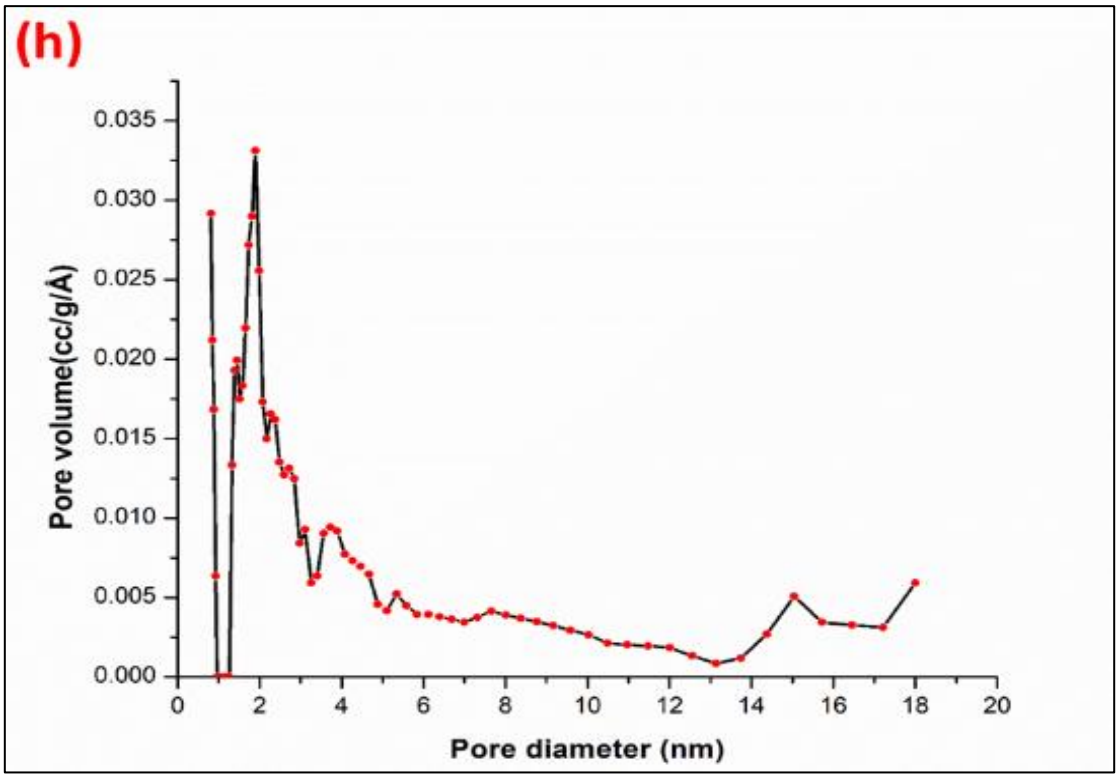


Figure 3.11: BET measurements of synthesized MSNPs

3.2.2.3. X-ray diffraction

A potent method for examining the crystalline structure of materials is XRD. In this instance, information about the crystallinity of the synthesized material was revealed by the XRD pattern. The XRD pattern clearly indicated that the material under investigation was amorphous. Amorphous materials lack a well-defined long-range order in their atomic arrangement, which is in contrast to crystalline materials that exhibit distinct diffraction peaks in their XRD patterns. In the XRD pattern of the amorphous silica powder, no sharp peaks or distinct patterns characteristic of crystalline structures were observed. However, a strong broad peak was evident at 22.17° (2θ) in the XRD pattern (Figure 3.12). This broad peak is a common characteristic of amorphous materials and further confirmed the absence of any crystalline structure in the synthesized material. Based on the XRD analysis and the absence of distinct diffraction peaks, the sample was identified as amorphous MSNPs. These MSNPs have a disordered atomic arrangement, which imparts unique properties and functionalities compared to their crystalline counterparts. The findings of this study align with similar XRD patterns reported by other research groups working with silica

nanoparticles. Studies by (Bogeshwaran *et al*., 2014; Thuadaij & Nuntiya, 2008) have also demonstrated similar XRD patterns for amorphous silica nanoparticles.

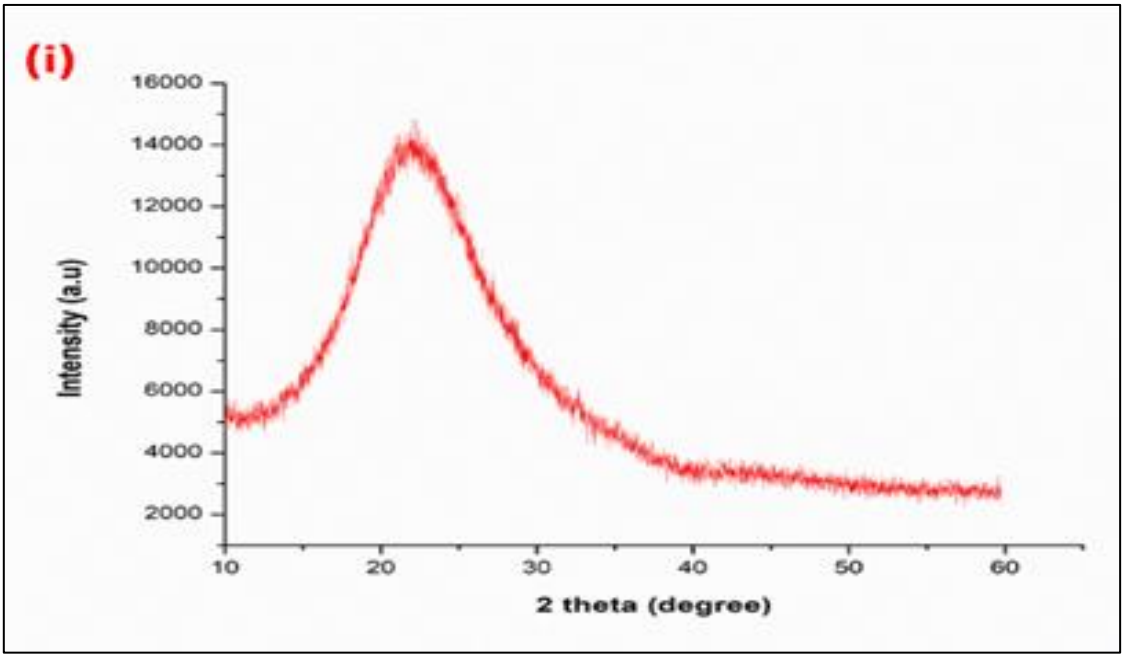


Figure 3.12: XRD analysis of synthesized MSNPs

3.2.2.4. Energy Dispersive X-ray

The Energy Dispersive X-ray (EDX) analysis conducted on the synthesized MSNPs provided valuable information about their elemental composition. The results of the analysis confirmed the presence of major elements that constitute the MSNPs, namely Silica (Si), Oxygen (O), and Carbon (C) (Figure 3.13). This data serves as strong evidence of the successful synthesis of the desired nanoparticles with the intended elemental composition.

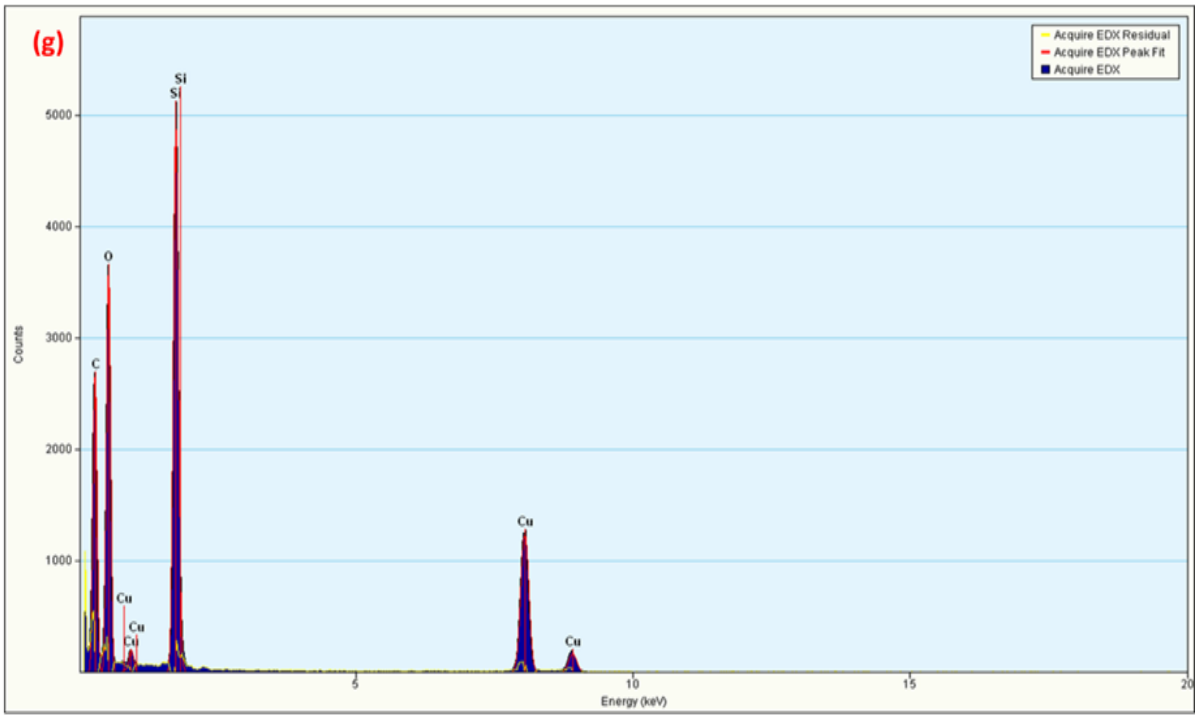


Figure 3.13: EDX confirmation for elemental composition of synthesized MSNPs

3.2.2.5. Zeta Potential

The zeta potential of the MSNPs was determined to be -27 mV. The zeta potential is a measure of the electric charge present on the surface of colloidal particles, including nanoparticles. A negative zeta potential value indicates a net negative charge on the surface of the nanoparticles. This negative charge provides colloidal stability, as like charges repel each other, reducing the potential for aggregation or clumping of the MSNPs. It ensures that the MSNPs remain well-dispersed and do not aggregate, enabling them to interact effectively with target sites or molecules in a controlled and precise manner.

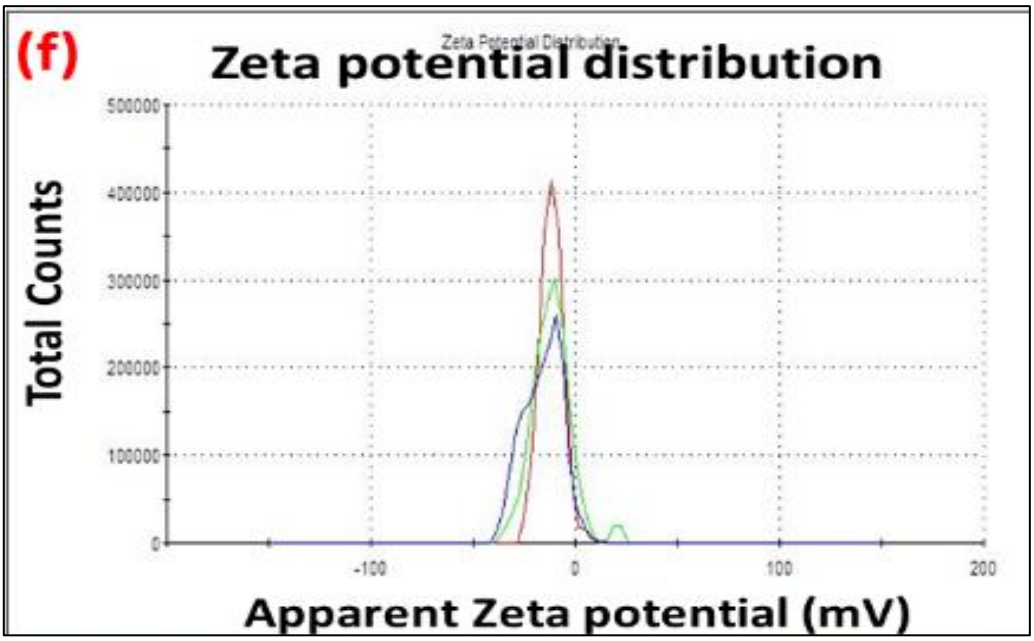


Figure 3.14: Zeta potential of synthesized MSNPs

3.2.3. Stability studies of MSNPs via transformative changes in particles during storage

The stability analysis of the synthesized MSNPs was conducted using Dynamic Light Scattering (DLS) at room temperature (25 ± 2ºC) over a period of 72 hours (Figure 3.15). Throughout this duration, the MSNPs showed notable stability, exhibiting no discernible alterations in their DLS data at various time intervals. This consistent behaviour attests to the sustained stability of the MSNPs up to the 72-hour mark. This outcome specifies that the MSNPs possess robust physical properties that resist aggregation or degradation under ambient conditions. The consistent DLS data further substantiates the durability of these nanoparticles, reinforcing their potential utility in various applications, particularly in foliar spray formulations. The chemical linking and structural depiction provided in Figure 3.16 provide understandings into the composition of the MSNPs.

3.2.4. Biocompatibility and toxicity measurements

The assessment of biocompatibility and non-toxicity was a pivotal aspect of this research work. Normal epithelial cells were exposed to these MSNPs at concentrations ranging from 5 to 20 µg mL^{-1} in order to evaluate the potential effects on cellular health. The evaluation encompassed two key parameters: cell viability which were determined through the MTT

assay, and the preservation of cellular morphology. The results obtained, as depicted in Figures 3.16a and 3.16b, showed the extremely porous MSNPs with no cytotoxic effects on the epithelial cells. This is due to the intrinsic properties of the highly porous MSNPs. The substantial porosity and distinctive structural characteristics result in an enhanced surface area which enables the efficient interactions with cells. The MTT assay showed the lack of cytotoxicity which is significant and emphasizes the MSNPs biological inertness at the examined concentrations and the preserved cellular shape offers further confirmation of these nanoparticles non-disruptive action within the cellular environment.

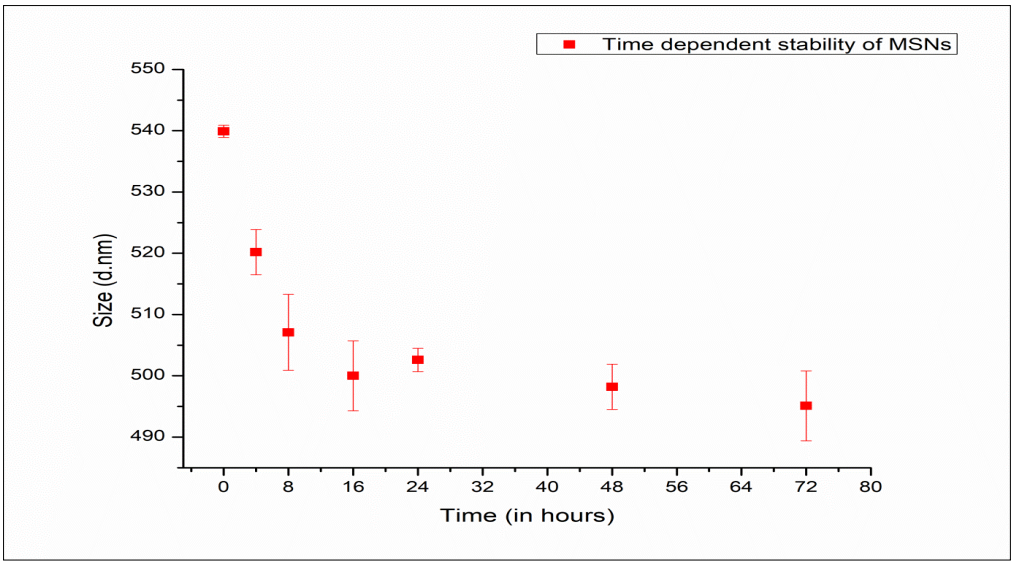


Figure 3.15: The stability of the synthesized MSNPs analysed using DLS over a time period of 72 h at room temperature (25 ± 2ºC).

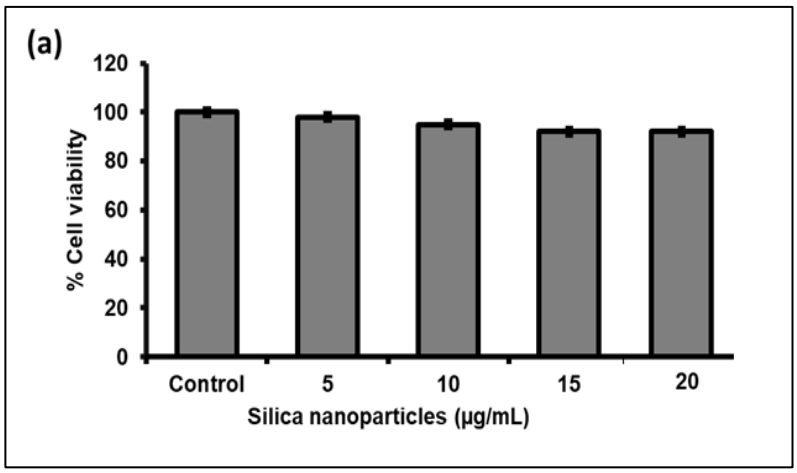


Figure 3.16 (a): Concentrations of the MSNPs for Biocompatibility / cytotoxicity

As shown in Figure 3.16 a and b, the analysis showed that at high concentrations of the MSNPs (10, 15, and 20 µg mL^{-1}), the percentages of viable cells were discovered to be 89.46% and 96.28%, where 15 and 20 µg mL^{-1} showed the same percentage i.e., 96.28%. In contrast to untreated cells (control), noteworthy morphological changes were seen when Hela cells were exposed to the MSNPs at these higher concentrations (15 and 20 µg mL^{-1}).The observed percentages of viable cells at the higher MSNP concentrations showed the interactions between the nanoparticles and the cells intensified. Despite this elevated exposure, the percentages of viable cells remained relatively high. This suggests that the MSNPs, even at increased concentrations, do not induce significant cytotoxic effects, thus maintaining a considerable proportion of viable cells. In terms of the morphological changes, the variations seen in Hela cells at greater MSNP concentrations could be as a result of the cells reaction to the nanoparticles. As they engage with and adjust to the nanoparticles, cells may experience morphological changes. The contrast between treated and untreated cells serves to emphasize the particular impacts of MSNP exposure.

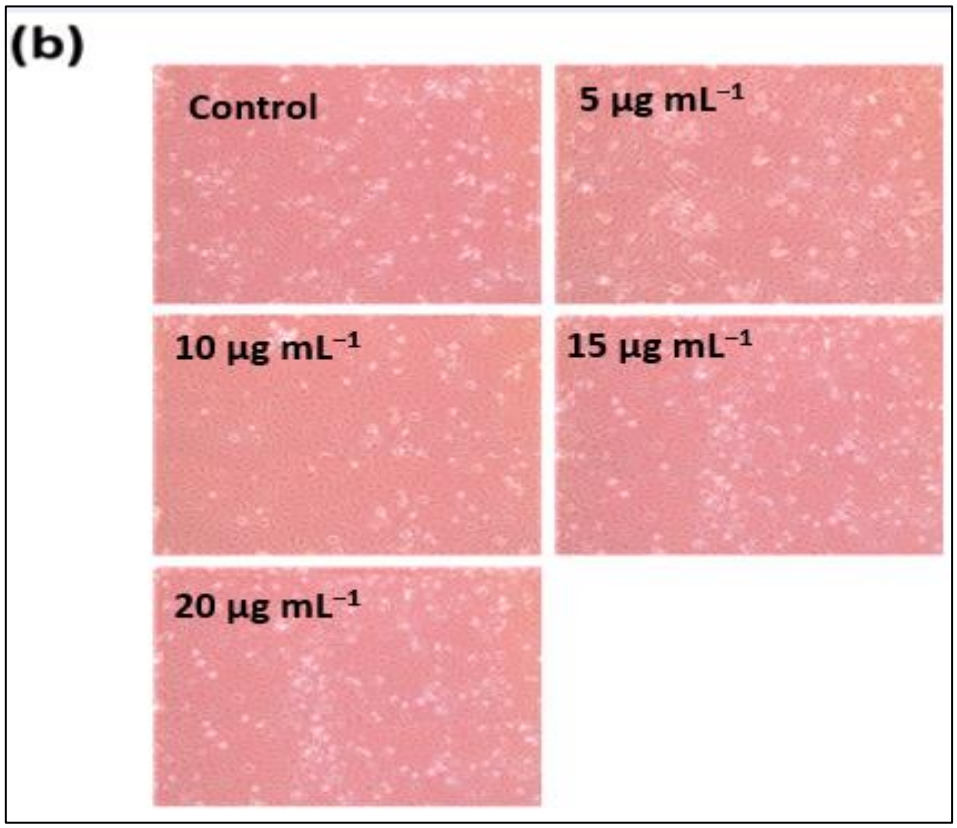


Figure 3.16 (b): Biocompatibility / cytotoxicity of the synthesized MSNPs

3.2.5. Development of latent finger impressions using MSNPs

Brushing method is used to adhere nanoparticles powder to fingerprint residue, improving adhesion to perspiration and oily materials like grease and oil. Mesoporous Silica Nanoparticles are crucial in this situation. They are then physically adsorbed into the ridges formed on the fingerprint surface. The MSNPs present in the fingerprints are subsequently exposed to 365 nm UV light. This contact causes the MSNPs to emit blue light, which successfully reveals the detailed pattern of the fingerprint impression. The physical adsorption of MSNPs onto the ridges is facilitated by the affinity of these nanoparticles for the greasy and oily components present in the residue, such as sweat and oil. This characteristic allows the MSNPs to swiftly adhere to the fingerprint, enhancing the fluorescence in MSNPs that can be easily visible under UV light application which is distinctive and stands out nicely against the fingerprint residue.

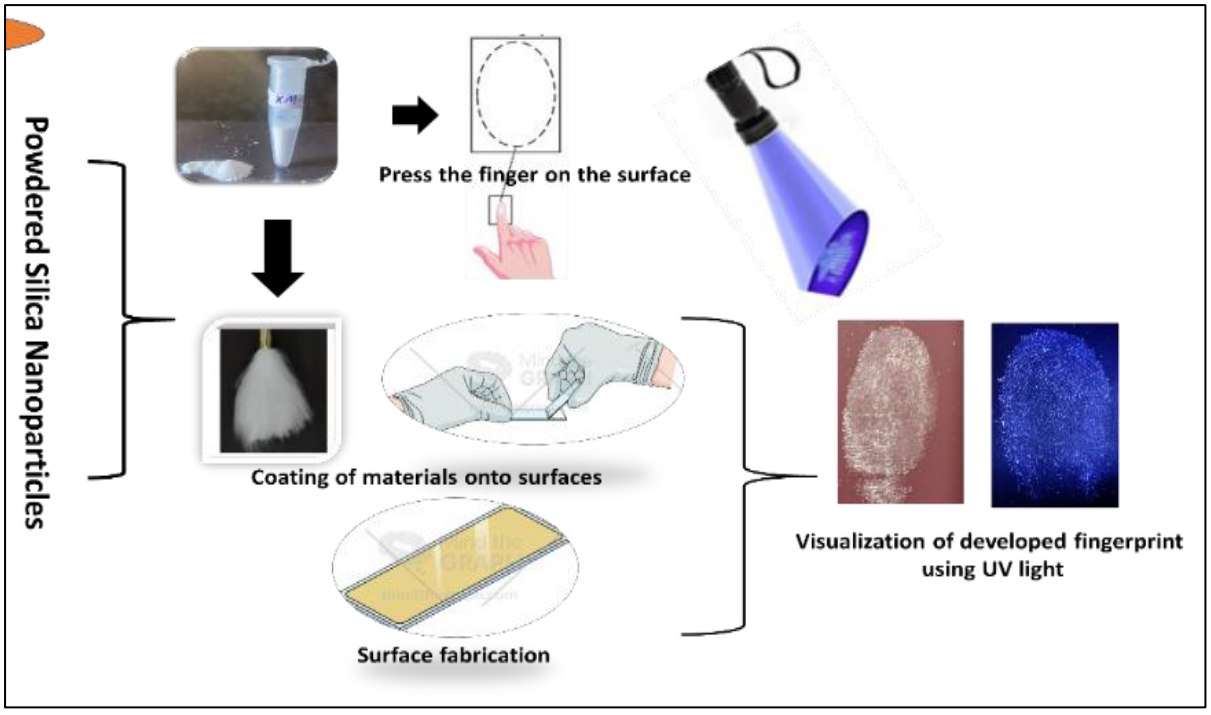


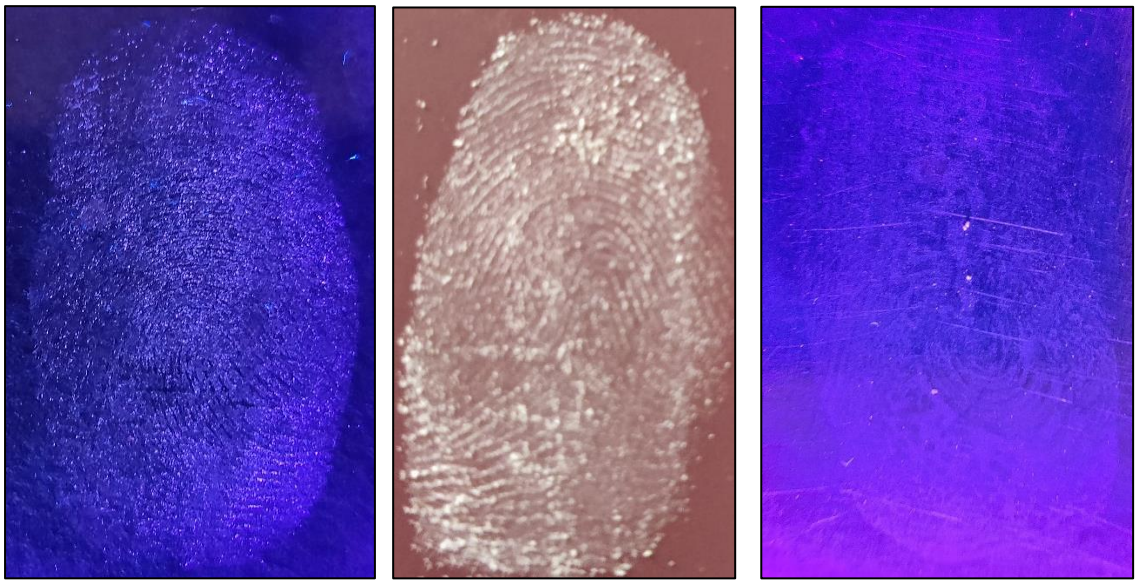
Figure 3.17: Application of MSNPs in detecting latent fingerprints.

The dormant finger impressions were developed on five different porous and non- porous surfaces including glass, paper, wooden surface, steel cup, and plastic lid using the MSNPs (Table 3.2). After developing the dormant finger impressions, they were visualized under a UV torch light (365 nm) and preserved in the .jpeg format through photographs using OnePlus 8T mobile camera (48 megapixel). The fingerprint patterns and ridge characteristics

could be observed by the naked eye which were not visible in natural light. The fingerprints present on plastic, glass, and metal surfaces were developed more accurately due to the suspension of the fingermark residue on the surfaces (Figure. 3.18) in comparison with other sample surfaces. In the latent fingerprint developed through this process level 1 (pattern) and level 2 (individual characteristics - bifurcation, trifurcation, dot, etc.) characteristics were clearly visible in them but level 3 (sweat pores) details were not clearly visible (Figure 3.19, 3.20). Results were found negative in case of wooden and paper surfaces (porous) that may be due to their high porosity hence it won't be able to sustain on the surface.

Table 3.2: Latent finger impressions developed using MSNPs nanoparticles.

S.No.	**Surface**	**Material**	**Level-I (pattern)**	**Level-II (ridge characteristics)**
1.	NON-POROUS	Silica Phone Cover	Visible	Visible
2.	NON-POROUS	Plastic Phone Case	Visible	Visible
3.	NON-POROUS	Glass Slide	Visible	Visible
4.	NON-POROUS	Stainless Steel	Visible	Visible
5.	NON-POROUS	Plastic Calculator cover	Visible	Visible
6.	NON-POROUS	Transparent poly bag	Not-Visible	Not-Visible
7.	POROUS	Black Paper	Not-Visible	Not-Visible
8.	POROUS	Paper bag	Not-Visible	Not-Visible



a. Glass b. Silica Phone Cover c. Steel Surface

d. Plastic e. Soft Plastic

Figure 3.18: Developed fingerprints on various non-porous surfaces using MSNPs (a. Glass, b. Silica Phone Cover, c. Steel Surface, d. Plastic, e. Soft Plastic)

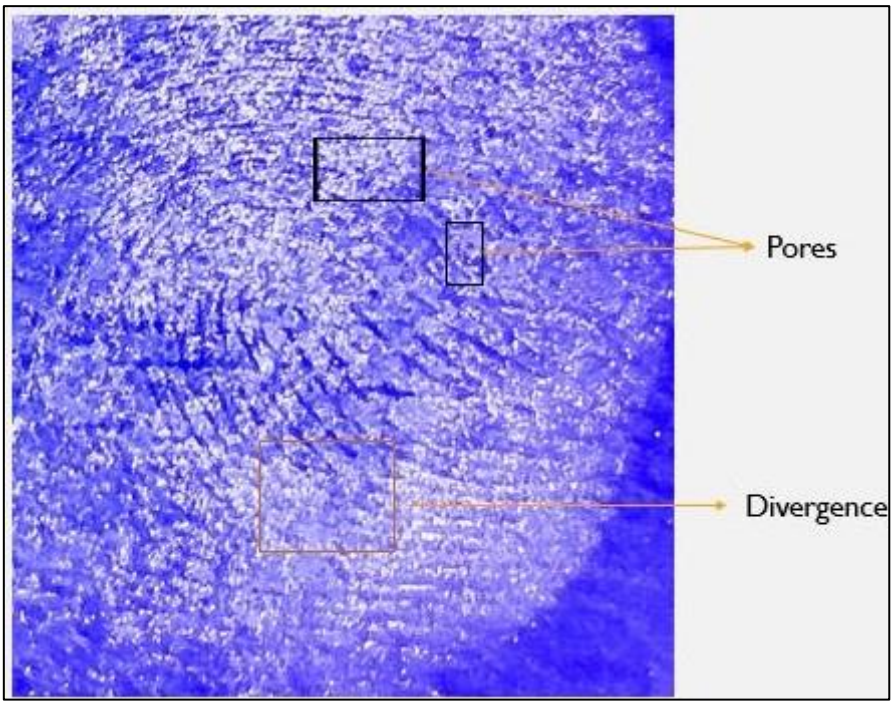


Figure 3.19: Individual Characteristics visible on glass surface

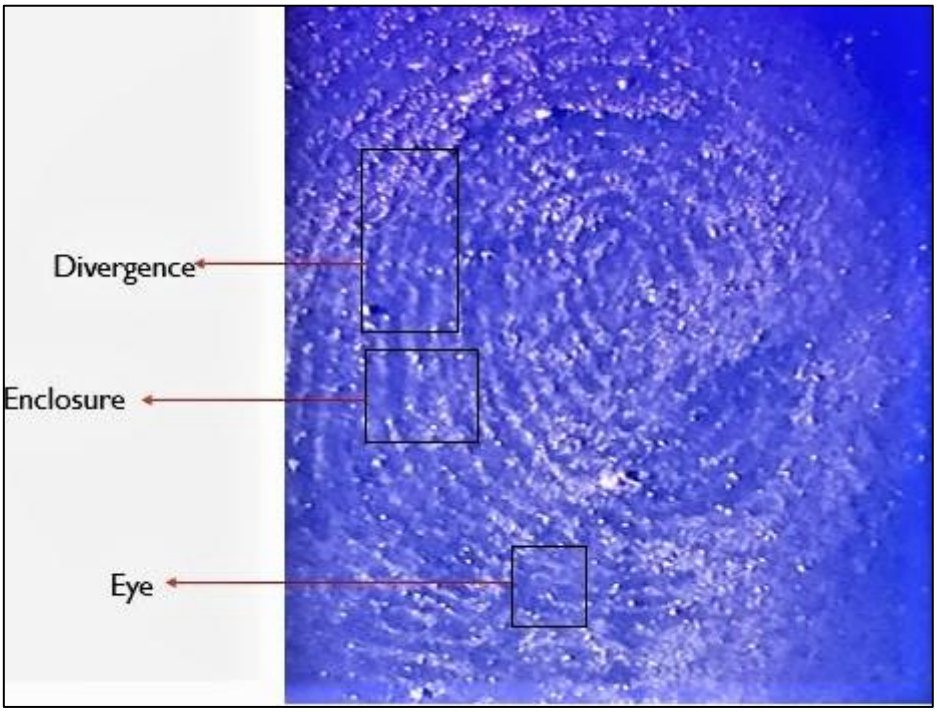
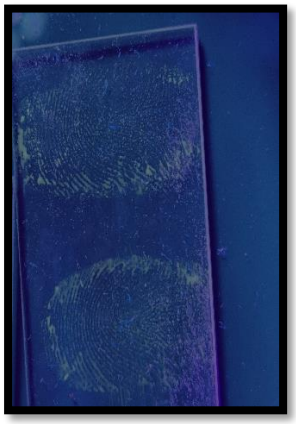
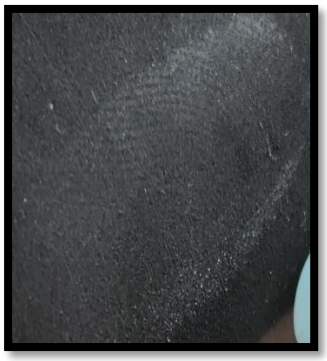
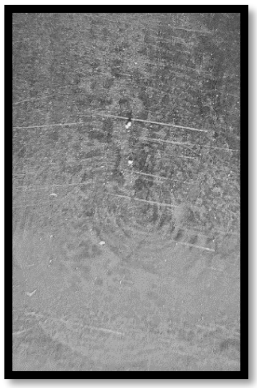
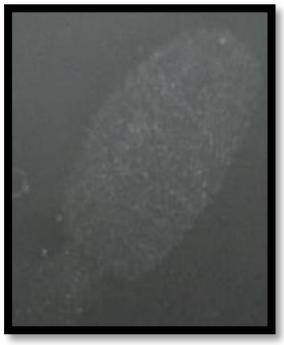
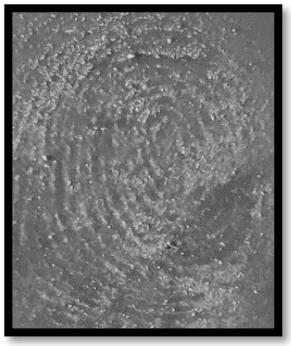


Figure 3.20: Individual Characteristics visible on plastic surface

Table 3.3: **Comparison of developed latent finger impression under Normal light and UV Light.**

	Normal Light	UV Light (365nm)	Grey Scale Image
Silica Phone Cover			
Glass Slide			
Stainless Steel			
Plastic Calculator cover			

MSNPs developed latent fingerprints on non-porous surfaces (glass, metal, plastic, and steel) with a clear appearance of class and individual characteristics as well as pores. Whereas fingerprints were not developed on porous surfaces. This may be due to the transparency of polybags and less R_f index difference of polybag with the light in UV-Visible spectrum. In the case of porous surfaces, surface porosity increases the surface area, thus resulting in the absorption of nanoparticles. The absorption of NPs leads to the distortion of the fingerprints in the form of agglomerates (X. Liu *et al*., 2022; Sargazi *et al*., 2022).

Numerous scientists have carried out similar investigations to demonstrate the value of MSNPs in the formation of latent fingerprint impressions. When compared to porous surfaces, the research by (Huang *et al*., 2015; Rajan *et al*., 2020; M. Zhang *et al*., 2017) demonstrated that non-porous surfaces produced superior results. (Rajan *et al*., 2020) reported monodispersed and spherical MSNPs from rice husks for high-definition latent fingermark development with comparable outcomes. On most non-porous surfaces like glass, metal, tiles, and semi-porous surfaces like painted wood, the silica nanoparticle powder was found to provide clear and precise images of latent finger impressions with little background discoloration, exposing outstanding ridge characteristics. Using the synthesized silica nanoparticle powder, excellent visibility of the minute details or ridges was seen.

In recent years, researchers have claimed biocompatible nature of MSNPs when tested on various cells lines and observed the potential usages of rode-like morphology in cancer theragnostic (Sargazi *et al*., 2022). Hence, MSNPs have shown their advantages in multiple applications including adsorption agent and sensors. Similarly, (X. Liu *et al*., 2022) developed silica-based nanostructures of graphene/SiO_2-Ag for increasing the adsorption of biomolecules. To achieve these major criteria, several researchers have developed variety of nanomaterials and nanocomposites for developing sensitive sensors. (Roostaee *et al*., 2022)*Roostaee et al.,* developed a nano sensor based on Co-MOF and graphene oxide for detecting the dopamine and uric acids in biological samples with the limit of detection (LOD) of 0.04 μM. Most of the micro-sized metal oxide powders blended with the color additives including dyes, pigments, and luminescent materials have been used to enhance fingerprint images.

CHAPTER-4

SYNTHESIS, CHARACTERIZATION, TOXICITY ASSESSMENT AND LATENT FINGERPRINTS DEVELOPMENT OF GRAPHENE NANOSHEETS (GNS)

4. SYNTHESIS, CHARACTERIZATION, TOXICITY ASSESSMENT AND LATENT FINGERPRINTS DEVELOPMENT OF GRAPHENE NANOSHEETS (GNS)

4.1. GRAPHENE NANOSHEETS

In recent years, graphene sheets and other carbon-based nano materials have gained importance due to the specificity of zero-dimensional carbon materials consisting of sp^2/sp^3 hybridized carbon atoms in the core with abundant functional groups on the shell and exhibited composition-dependent fluorescence properties. Graphene based materials trigger great concern in a wide range of applications ranging from bio-imaging, sensing, drug-delivery, photocatalysis, energy storage, and fluorescent ink to disease diagnosis due to their unique properties such as robust chemical inertness, non-toxicity, extreme biocompatibility, photoluminescence, simple synthesis, simple surface functionalization, and good water solubility and great stability without photobleaching. However, low fluorescent quantum yields demand subsequent strategies, including functionalization or surface passivation to enhance the optical properties of GNSs. Currently, heteroatom-doped graphene nanomaterials are a hotspot; this provides a feasible and facile way to tune their intrinsic properties to achieve new and multifunctional applications. In this line of interest, a few researchers have explored the applications of graphene-based nanomaterials for fingerprinting applications. Graphene nano-sheets (GNS) have a strong adherence to fingerprint residues as well as high-resolution imaging and improved visibility. GNS have gained a lot of interest as they are non-metallic in nature, GNS also exhibit comparatively low toxicity and superior biocompatibility when compared to conventional organic dyes and semiconductor quantum dots (L. Yang *et al*., 2021). The graphene-based compositions have the ability to develop latent fingerprints and it can be seen using various light sources which gives imprints the change of color depending upon the source of light, allowing it background-free photos and maximizing the accuracy of fingerprint analysis.

4.1.1. Chemicals and reagents

Reagents used in current research work were of the AR grade and these are used without further purification or treatment. Specific analytical grade (AR) chemicals, such as ethanol, mercuric chloride, methanol, and hydrochloric acid (HCl), were purchased from Merck,

Mumbai, India. A uniform and regulated medium was ensured by using Millipore water which has a conductivity of 18.2 MΩ cm at 25 °C, to prepare aqueous solutions. Additionally, Whatman® Grade 1 filter paper was bought from Sigma-Aldrich in St. Louis, Missouri, the United States, to help with several filtration procedures.

4.1.2. Sample collection of latent fingerprints

The standard protocol has been followed for the sample collection (same as 3.1.2.).

4.1.2.1. Development of latent fingerprint using nanoparticles

The standard method has been followed for the development of latent fingerprints using nanoparticles (Same as 3.1.2.1)

4.1.2.1.1. Synthesis of nanoparticles

Bottom-up synthesis has been utilised to create Graphene nanosheets. The graphene nanosheets were synthesized by Hydrothermal processing which is an unconventional method to synthesize nanocrystalline inorganic materials. Hydrothermal method is based on this premise wherein the materials are dissolved in water under high temperature and pressure conditions.

This study used chickpeas as a precursor and a modified pyrolysis process to successfully synthesise water-soluble graphene nanosheets (GNS). 2 grams of powdered chickpea sample were measured using weighing balance were put into a covered quartz boat. After that, the boat was heated to a temperature of 800°C for two hours at a controlled rate of 5° per minute in an inert environment. In order to add hydrophilic groups to the surface of the graphene nano-sheets, the synthesised soot was collected after the pyrolysis step and treated with nitric acid. Typically, 100 mL of a 60% nitric acid solution was prepared from the 100% nitric acid solution using-

($C1V1 = C2V2$, C_1 = concentration of the original nitric acid solution (100%), V_1 = volume of the original nitric acid solution needed (in mL, which is V mL), C_2 = concentration of the final nitric acid solution (60%), V_2 = volume of the final nitric acid solution (100 mL), (100% concentration)V = (60% concentration)(100 mL), V = (60/100) * 100 mL, V = 60 mL, amount of water needed for it calculated by -Amount of water = 100 mL – V, Amount of

water = 100 mL - 60 mL = 40 mL, then 60 mL of the 100% nitric acid solution and 40 mL of water were measured and mixed thoroughly to obtain 100 mL of a 60% nitric acid solution.)

were combined with 1 gram of the soot (measured in weighing balance), and the mixture was refluxed for 12 hours at room temperature. The leftover slurry underwent additional processing while the supernatant was carefully removed using centrifugation after refluxing. The supernatant was evaporated using a water bath until a concentrated slurry was obtained in order to get rid of extra acid and achieve water solubility. The slurry was then mixed with 500 mL of water, and the combination was once more evaporated. The efficient elimination of any excess acid present was made possible by this repeated process. The pH of the slurry was carefully monitored throughout this procedure, and when it achieved a neutral value of 7.0, the slurry was left to dry at room temperature. The water-soluble GNS were successfully gathered as a result of this carefully optimised process, with a yield of about 60%. Due to their water solubility and altered surface properties achieved by the addition of hydrophilic groups during the nitric acid treatment these graphene nano-sheets show considerable promise for a variety of applications. This new method of synthesising functional graphene nano-sheets utilising chickpeas as a precursor offers a sustainable and ecologically friendly way to do so with potential uses in a variety of industries.

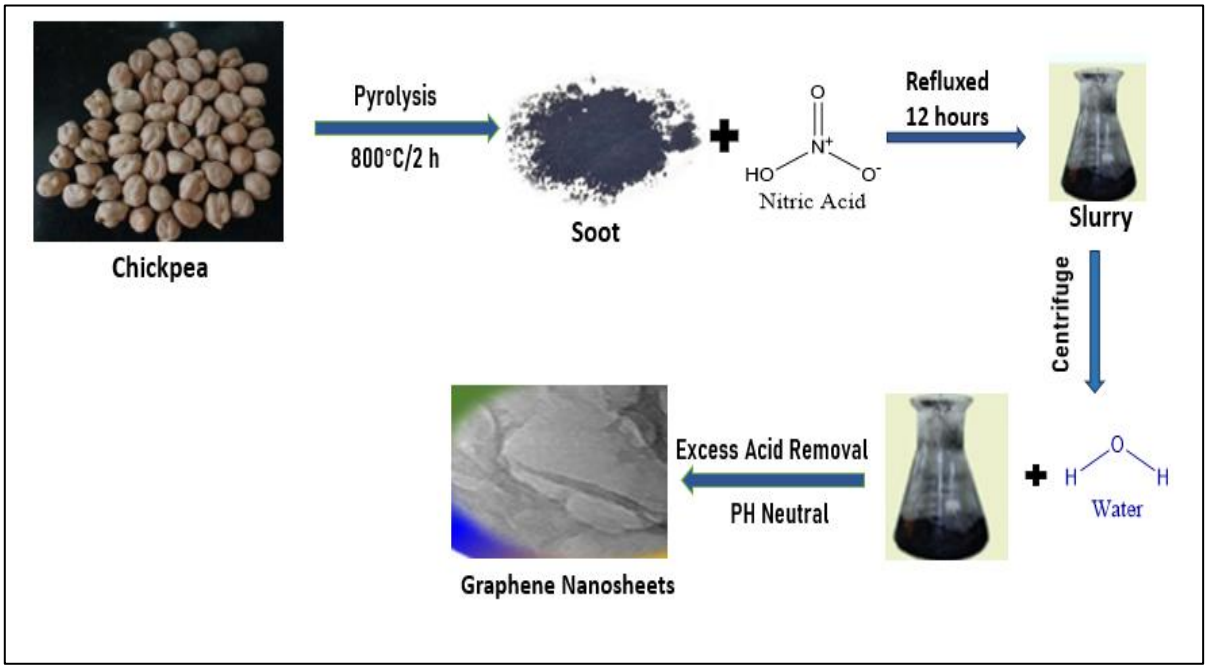


Figure 4.1: Schematic representation of synthesis of GNSs

4.1.2.1.2. Characterization of synthesized GNS

The microstructure and morphology of the synthesized GNS were thoroughly characterized using advanced analytical techniques. TEM and High-Resolution Transmission Electron Microscopy (HR-TEM) were employed for this purpose, utilizing a state-of-the-art FEI Tecnai F30 microscope operated at 300 kV. These powerful imaging techniques allowed to examine the atomic-level structure and detailed morphology of the GNSs, providing valuable insights into their size, shape, and arrangement.

To investigate the optical properties of the GNSs, various spectroscopic measurements were carried out in aqueous solutions. Firstly, the optical absorption spectra were recorded using a UV-vis spectrophotometer. This analysis allowed to study how the GNSs interacted with light at different wavelengths, shedding light on their absorption characteristics. It measures the absorption or transmission of ultraviolet (UV) and visible (Vis) light by a sample. It provides valuable information about the concentration, composition, and chemical properties of substances. The working principle of a UV-Vis spectrophotometer is based on the Beer-Lambert Law, which states that the absorption of light by a sample is directly proportional to the concentration of the absorbing species and the path length of the light through the sample. The principle can be mathematically expressed as

$$A = \varepsilon l c, \qquad (4.1)$$

where A is the absorbance, ε is the molar absorptivity or extinction coefficient, l is the path length, and c is the concentration of the absorbing species.

Figure 4.2- UV-Vis Spectrophotometer.

Furthermore, the emission spectra of the GNSs were captured using a Varian fluorescence spectrometer in an aqueous solution at room temperature. This fluorescence analysis offered information about the GNSs ability to emit light when excited by an external energy source, revealing valuable details about their luminescent behaviour.

Photoluminescence (PL) images of the GNSs in the aqueous solution were obtained using a Leica inverted optical microscope (Leica DM 2500, Leica Microsystems Ltd.) on a glass plate. This imaging technique provided researchers with visual representations of the luminescence emitted by the GNSs, facilitating a qualitative understanding of their photoluminescent properties.

In addition to the above techniques, Fourier Transform Infrared Spectroscopy (FTIR) was conducted using a spectrometer. FTIR is a powerful method for analysing the chemical composition and functional groups present in the GNSs. By studying the infrared absorption and vibrational frequencies, researchers could gain insights into the molecular structure and chemical bonding within the GNSs.

This comprehensive array of characterization techniques played a vital role in unveiling the physical, optical, and chemical properties of the synthesized GNSs. The findings from these analyses significantly contributed to a deeper understanding of the GNSs potential applications and their behaviour in aqueous environments.

4.1.2.2. Cell lines experiments for cytotoxicity and morphological evaluation of GNSs

The bronchial epithelium cells (BEAS-2B) were cultured in a specific growth medium to maintain their viability and support their growth. The culture medium used was RPMI-1640, a nutrient-rich solution that provided essential nutrients and growth factors necessary for the cells to thrive and the medium was also supplemented with 10% (v/v) foetal calf serum, which further enriched the culture environment and supported cell growth. To prevent contamination and ensure the health of the cell culture, 1% penicillin-streptomycin solution was added to the medium, acting as an antibiotic safeguard against potential bacterial or fungal infections.

The cytotoxic effect of GNSs was investigated on the BEAS-2B cells by MTT assay, a widely used method to assess cell viability and cytotoxicity. The experiment involved

incubating 6×10^4 BEAS-2B cells per well with different concentrations of GNSs (ranging from 5 to 50 µL/mL) at a controlled temperature of 37°C in a carbon dioxide (CO_2) incubator for 24 hours. This incubation period allowed the GNSs to interact with the cells and potentially induce cytotoxic effects. After the incubation, the cells were treated with an MTT solution, which is a yellow tetrazolium dye. Metabolically active cells converted the MTT dye into dark blue-coloured formazan crystals. The formazan crystals were then dissolved in 50 µL of dimethyl sulfoxide (DMSO) to extract the coloured product from the cells. Subsequently, the absorbance of the resulting solution was measured at a wavelength of 540 nm using a multi-microplate reader.

4.1.2.2.1. Bacterial strain and antibacterial efficiency of GNSs

The goal of this study was to examine the behavior of the food-hazardous bacterium Bacillus cereus. This pathogen was cultured and grown in Luria-Bertani (LB) medium, which was purchased from Acumedia, Lansing, Michigan, USA. The pathogen could develop in the LB medium to provide the appropriate nutrients and environmental factors. As 37°C is the ideal temperature for *Bacillus cereus* growth, this temperature was kept constant during incubation. The pathogen was kept on LB agar at a chilled temperature of 4°C to preserve it. The strain was revived by taking it off the agar plate when it was required for the tests, and a loop full of bacterial cells was then transferred to brand-new LB medium. An additional 24-hours incubation at 37°C was performed after this reactivation step to give the pathogen time to proliferate and reawaken. For consistent growth and stability, all of the *Bacillus cereus* sub-cultures were then maintained in LB medium. Phosphate-buffered saline (PBS) was utilized as a negative control as the standard in all of the research studies. PBS is a solution that is used to keep the osmotic balance in check and give cells a steady environment without changing how the pathogen behaves.

4.1.2.2.2. Antibacterial and bacteria-killing kinetics of GNSs

To evaluate the antibacterial activity of synthesized GNSs against the pathogen *Bacillus cereus*, this study has been done. The GNSs were produced in LB broth, at varied concentrations ranging from 0 to 50 µg/mL. This gave the opportunity to assess how various GNS concentrations affected the bacterial community. An inoculum of *B. cereus* in the mid-log phase, containing roughly 10^6 cells/ mL, was introduced to each GNS dilution in the LB broth to begin the antibacterial testing. The combination was then kept at 37°C for an

incubation period to mimic bacterial growth and metabolism-friendly conditions. The cultures were examined to see if *B. cereus* at various GNS concentrations had grown visibly after a 24-hours incubation period. The GNS concentration deemed to effectively inhibit the bacterial population was that at which there was no discernible bacterial growth. This concentration was taken as the minimum inhibitory concentration (MIC), or the amount of an antimicrobial agent needed to stop bacteria from growing visibly. A colony counting experiment was run to validate and quantify the results from the visual inspection. Using the pour plating technique, the bacterial cultures from each GNS concentration were plated on LB agar substrate. In order to do this, liquid bacterial culture was poured onto an agar plate and let to set. The number of bacterial colonies that developed on the agar plate for each GNS concentration was counted after incubation. The antibacterial action of the GNSs at the particular doses was validated by a considerable decrease in the number of bacterial colonies as compared to the control (untreated) group. both the visual observations and colony counting assays was conducted to fully assess the antibacterial activity of the synthesized GNSs against *Bacillus cereus*.

The time-dependent mortality of *B. cereus* in the presence of GNSs was also assessed by conducting the series of experiments over different time intervals to observe the effect of GNSs on the viability of the bacterial cells. Initially, tubes containing LB broth supplemented with GNSs at the effective concentration were inoculated with a known quantity of *B. cereus* bacterial cells (approximately 10^6 cells). These tubes were then incubated at a temperature of 37°C, providing an environment conducive to bacterial growth and metabolism. At specific time points (0, 30, 60, 90, and 120 minutes), 100 µL of the bacterial cultures were withdrawn from the tubes. These samples were then serially diluted to reduce the concentration of bacteria and ensure individual colonies could be distinguished on the agar plates. The diluted samples were spread onto LB agar plates, which were subsequently incubated at 37°C for 24 hours to allow bacterial growth. Following the incubation period, viability assays experiment was conducted by counting the bacterial colonies on the LB plates. The number of colonies represented the viable bacterial cells that were able to grow and reproduce despite the presence of GNSs. In parallel, control tubes containing only the *B. cereus* bacterium without the addition of GNSs were set up under the same experimental conditions. These control tubes allowed to compare the bacterial growth in the absence of GNSs and serve as a reference for the effect of GNSs on bacterial mortality. To ensure the reliability of the

findings, the experiment was performed using three replicates, providing a robust statistical basis for the results.

4.1.2.2.3. Fluorescence microscopy staining assays for live/dead bacterial cells

The number of living and dead Bacillus cereus cells was counted using acridine orange/ethidium bromide (AO/EB) fluorescence labelling. *B. cereus* cells (10^6 cells/mL) grown overnight were treated with or without GNSs at the MIC and twice the MIC Using pre-optimized settings, the therapy was administered for 60 minutes at a temperature of 37°C. After treatment, the bacteria were centrifuged, cleaned in phosphate-buffered saline (PBS), and dyed with the Live/Dead® BacLightTM Bacterial Viability Kit L13152. Acridine orange labelling of viable cells produced green fluorescence, whereas ethidium bromide staining of non-viable cells produced red fluorescence. This staining procedure allowed to distinguish between live and dead cells. Confocal laser scanning microscopy was used to observe the labelled cells, and images were taken for analysis. Zeiss LSM Image Examiner software (Version 4.2.0.121) was used to further process the collected pictures in order to quantify and analyse the distribution of live and dead cells. All experiments were done three times independently, and at least three separate fields were evaluated for each culture, in order to ensure the accuracy and repeatability of the findings.

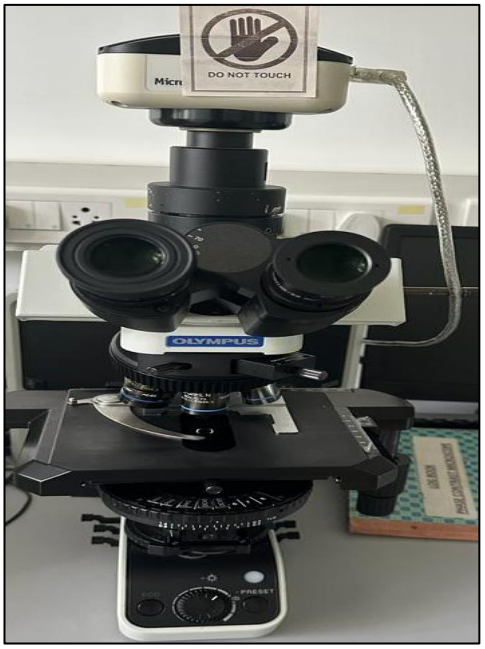


Figure 4.3: Confocal laser scanning microscopy

4.1.2.3. Development of dormant finger-impressions using GNSs

The application of synthesized graphene nano-sheets (GNSs) was assessed for detecting finger impressions on various surfaces, including porous, semi-porous, and non-porous materials. To conduct the assessment, a hairbrush was used to apply the GNSs nano-powder onto the different surfaces that has latent finger impressions collected from the volunteers by wiping the fingertips across the nose and forehead to transfer more of the fluids onto the surfaces. The nano-powder adhered to the substances secreted by the sebaceous, eccrine, and apocrine glands found in finger impressions. By employing the hairbrush method to disperse the GNSs nano-powder, latent finger impressions were successfully retained on multiple substrates. The white color of the nano-powder provided a stark contrast against both coloured and dark surfaces, making the developed finger impressions clearly visible and easy to analyse. Moreover, when using the nano-powder to develop the fingermarks, the resulting ridge features of the impressions exhibited minimal background disturbance. This reduced interference made it easier to identify and distinguish individual ridge patterns in the fingerprints, increasing the accuracy and reliability of fingerprint analysis.

4.2. RESULTS AND DISCUSSION

4.2.1. Synthesis of the synthesized GNSs

The pyrolysis of chickpea was performed at different temperature ranging 600-900^{o}C for different duration ranges from 30 minutes- 2.5 hours in which the black powder yielded at 800^{o}C pyrolyzed for 2 hours was the optimal one for the current research work. This high-temperature treatment plays a pivotal role in transforming the precursor material into the desired black powder. The process involves complex thermal decomposition reactions that lead to the formation of carbon-rich structures, laying the foundation for subsequent modifications. Further, the water solubility of synthesized GNSs was achieved by mild acid treatment with concentrated nitric acid. This treatment introduces oxygen-containing functional groups onto the surface of the GNSs, imparting them with enhanced solubility in aqueous environments. Additionally, the oxidation process brings forth high-density negative surface functionalities, further augmenting the GNSs compatibility with various chemical environments and potential applications. Oxidation endows GNSs with high-density negative

surface functionalities along with PL properties. These properties entail the ability of the GNSs to absorb photons and subsequently emit light, which can be visually observed. The introduction of functional groups through oxidation introduces energy states within the GNS structure, leading to the photoluminescence phenomenon.

4.2.2. Characterization of the synthesized GNSs

4.2.2.1. Morphological characterization of GNSs

The structural features of GNSs were precisely characterized through the TEM and HR-TEM microscopy. The analyses were employed to gain detailed insights into the morphology and graphitic properties of the GNSs. Figure 4.4(a) showed a TEM image that demonstrates the GNSs characteristic spherical structure without any visible morphological imperfections. This finding highlights the integrity and purity of the synthesised nanosheets. Notably, static calculations revealed that the size distribution of the GNSs fell between 10 and 50 nm, as shown in Figure 4.4(b). This quantitative comprehension of size offers a crucial appreciation of the dimensional characteristics of the nanosheets. Furthermore, the HR-TEM image presented in Figure 4.4(c) explores deeper into the internal structure of the GNSs. This analysis reveals the graphitic nature of the nanosheets, with the observed lattice fringes confirming a high degree of graphitization. The measured distance between adjacent lattice fringes, determined as 0.31 nm, further corroborates the quality of graphitization achieved. This finding aligns with the work by (Das *et al*., 2020), which emphasizes the significance of this characteristic as a marker of graphitic integrity.

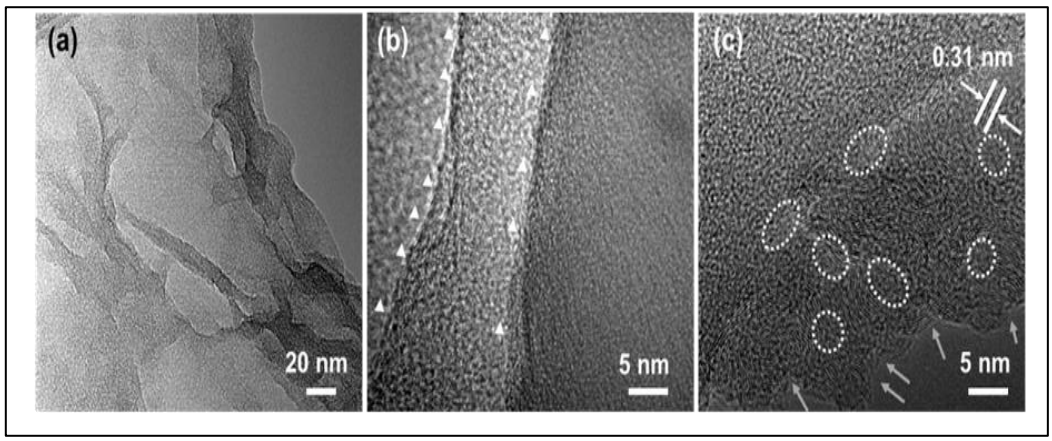


Figure 4.4(a): Low-resolution TEM image of GNSs; (b) high-resolution TEM image of GNSs; (c) HR-TEM image of GNSs showing interlayer spacing

4.2.2.2. Structural characterization of GNSs

Surficial functional groups of GNSs were identified with Fourier transform-infrared (FT-IR) spectroscopy. The development of π conjugated structure was confirmed by the existence of aromatic C=C vibrations peak centred at 1609 cm^{-1} and in-plane bending vibrations of aromatic C-H at 563 cm^{-1}. The broad band at 3435 cm^{-1} was assigned to the stretching vibrations of O-H. The peaks at 2917 cm^{-1} and 2851 cm^{-1} are ascribed to the aliphatic C-H stretching and the merged peak centred at 1726 cm^{-1} is attributed to C=O stretching. The band at 573 cm^{-1} corresponds to bending vibrations of =C-H. Peaks at 1120 cm^{-1} and 1039 cm^{-1} are ascribed to C-O and C-C stretching vibrations. The FTIR spectrum revealed the co-existence of the high density of oxygenous functional groups enables better stabilization of GNSs in water.

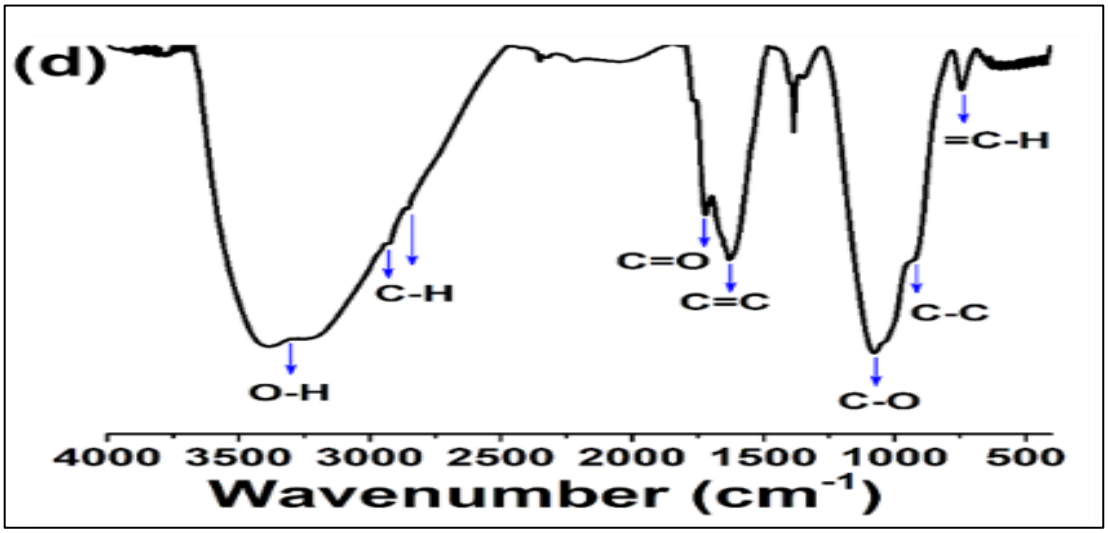


Figure 4.4(d): FTIR spectrum of GNSs

The characteristic D band (high intensity) and G band (low intensity) are observed in Raman spectra of GNSs (Figure 4.4(e)), which clearly reflect the defective nature of GNSs (Chowdhury *et al*., 2021). The XRD pattern of GNSs is shown in Figure 4.4(f), which exhibits a broad peak at 2Θ = 24.8 and another weak peak at 2Θ = 44, which represents the (002) and (100) plane of carbon.

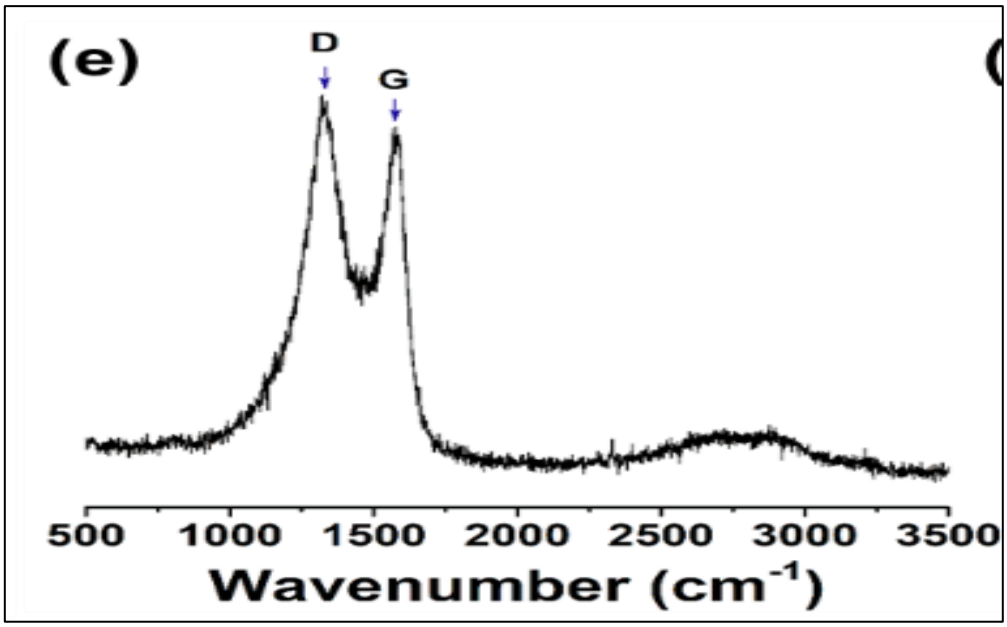


Figure 4.4(e): Raman spectrum of GNSs

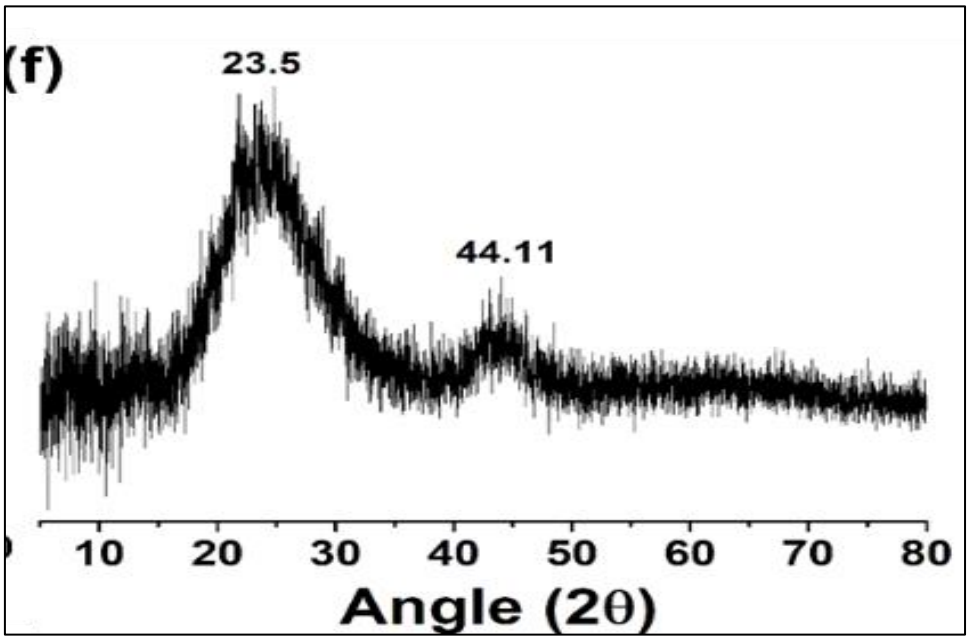


Figure 4.4(f): XRD spectrum of GNSs

4.2.2.3. Optical characterization of GNSs

Figure 4.5(a) showed the GNSs UV-Vis absorption spectrum which highlights different absorption traits that provide insight on the structure of the materials. Notably, a strong absorption band observed at ~ 200 nm and it has a continuous tail that spans the whole visible spectrum which links certain electronic transitions occurring within the GNSs.

The absorption band at 200 nm is a representative of π-π* transitions, which entail the excitation of electrons from the lower energy valence π -bond to the higher energy π *-antibond state and n-n* transitions, which involve the excitation of electrons from non-bonding states to higher-energy anti-bonding states, are responsible for the continuous tail that extends into the visible range. The presence of conjugated carbon-carbon (C=C) and carbon-oxygen (C=O) bonds within the GNSs is linked to these transitions. The unique electronic structure of the GNSs is further highlighted by these transitions, indicating the presence of these conjugated functional groups. An aspect of the absorption spectrum is the absence of any background absorption, which signifies the purity and lack of morphological impurities in the GNSs. This absence of background absorption underscores the high quality and integrity of the synthesized nanosheets, as there are no extraneous compounds or contaminants that could contribute to background signals. The research of (J. Chen *et al*., 2017; Lv *et al*., 2016), which examines the UV-Vis absorption properties of graphene-based materials and their electronic transitions, is consistent with our findings. Together, the observed absorption features and the lack of background absorption offer a thorough grasp of the electronic characteristics and purity of the GNSs, expanding the range of possible applications.

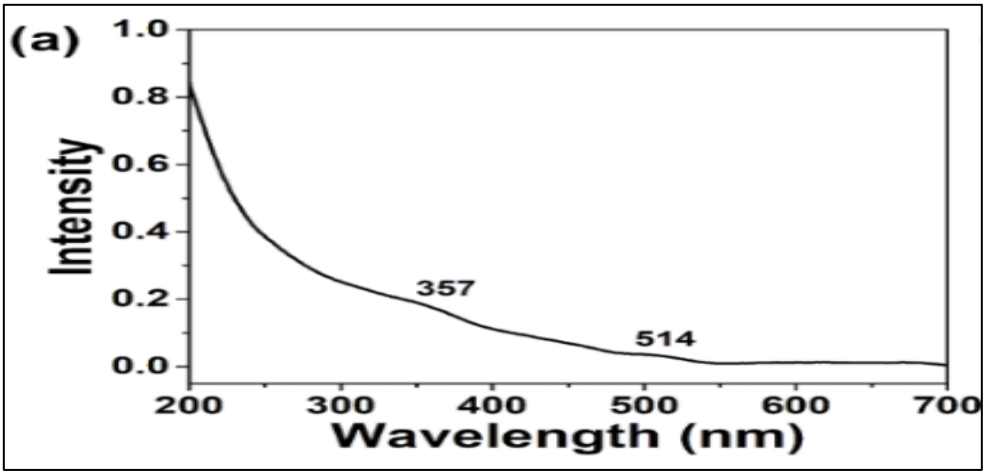


Figure 4.5(a): UV-Vis absorption spectrum of GNSs

The PL spectra in Figure 4.5(c) showed the excitation-independent emission spectra ranging from 360 to 620 nm excitation wavelengths at a continuous increment of 20 nm. The maximum emission was centred at ~708 nm, while the maximum emission intensity was

observed at ~475 nm. Excitation wavelength-dependent emissions of GNSs attributed to the different photon absorption mechanisms.

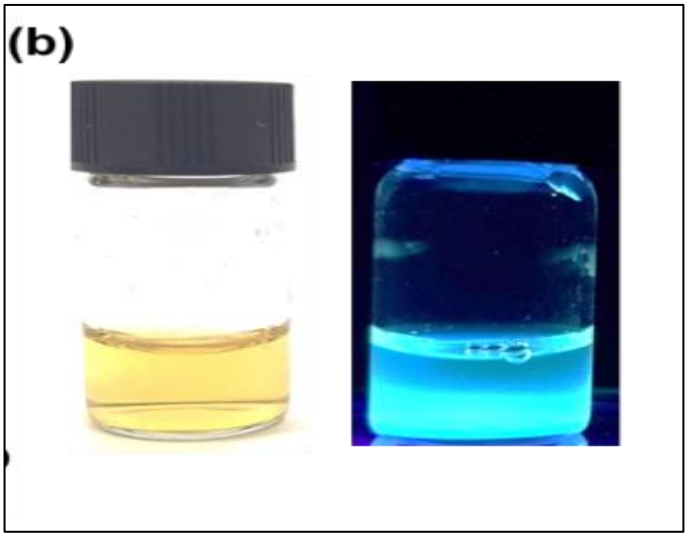


Figure 4.5(b): Synthesized fluorescence nanostructures of GNSs under UV lamp

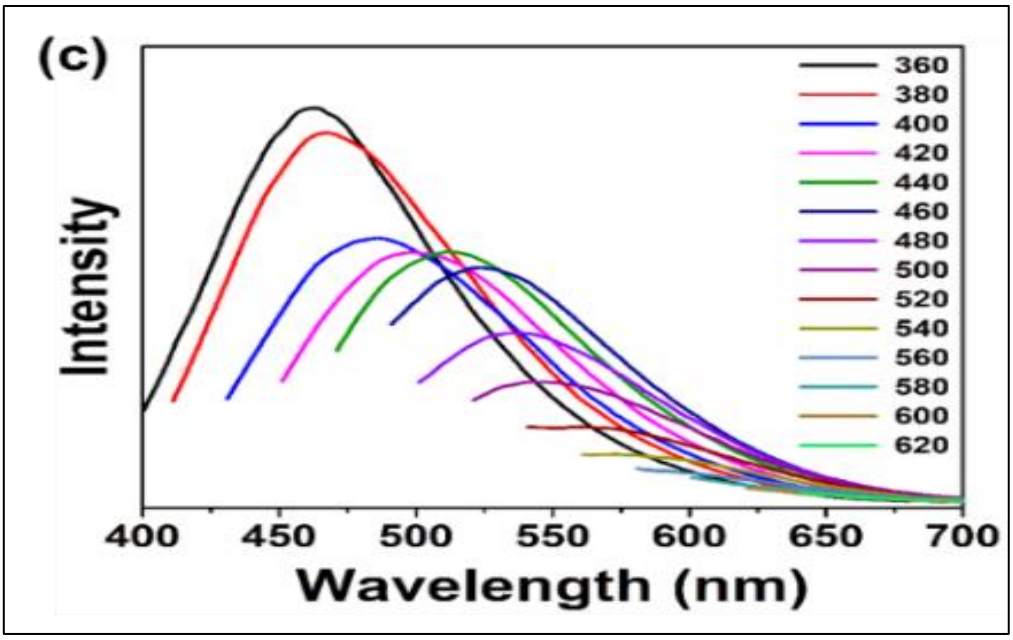


Figure 4.5(c): Emission spectra of GNSs excited by different wavelengths. Photostability test of GNSs

The quantum yield of GNSs was measured to be 22% with reference to quinine sulphate, indicating the strong quantum confinement of particles. The optical properties of GNSs were also investigated under the continuous irradiation of high intensity UV light and in the

presence of high ionic strengths. The emission intensity centred at 475 nm remains almost similar after 1 hour of continuous irradiation of UV light. No perceptible changes in PL emission intensity were observed under the influence of high ionic strength (0.5 M to 3.5 M) with Na^+, K^+, Ca^{2+}, and Mg^{2+} as shown in Figure 4.5(e) and (f).

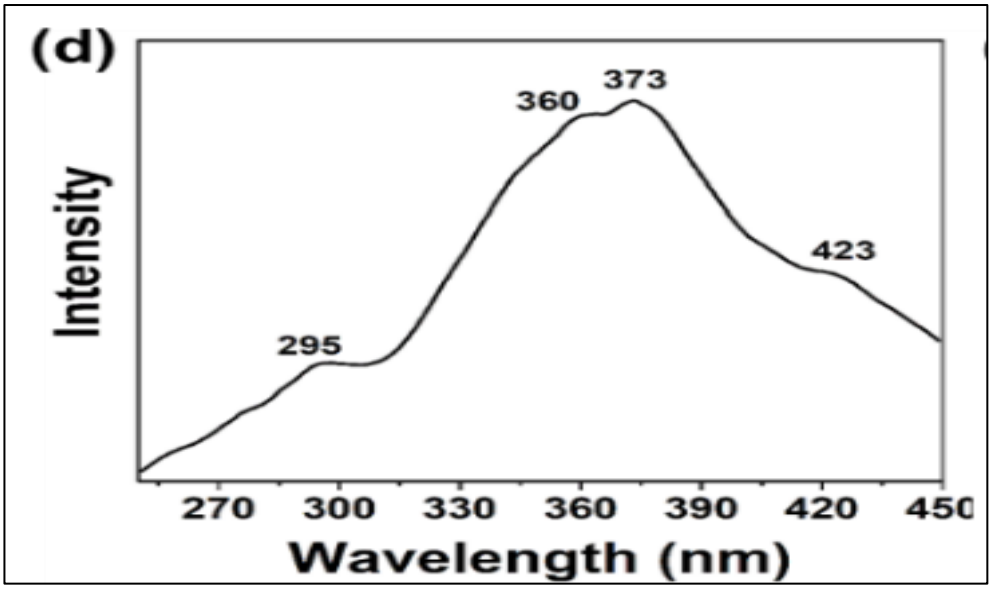


Figure 4.5 (d): Under continuous UV light (365 nm) irradiation

GNSs exhibited good photostability without any change in visual appearance after several months when stored in a closed vessel at room temperature. Hence, GNSs could be a potential PL probe at various physical salt concentrations. The green and red fluorescence optical micrographs as shown in Figures 4.5(e) and 4.5(f), under different band-pass filters reveals the highly florescence nature of GNSs.

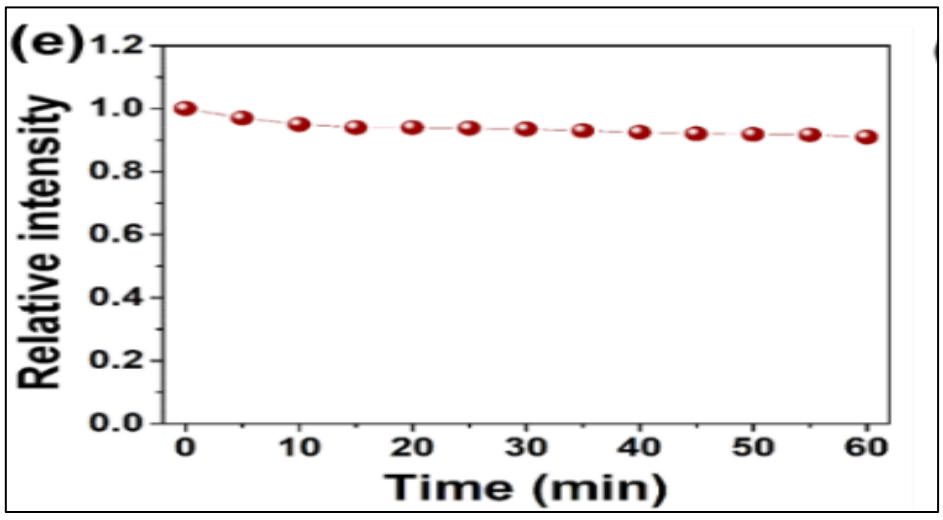


Figure 4.5 (e): In the presence of high ionic strength of Na^+, K^+, Ca^{2+}, and Mg^{2+}.

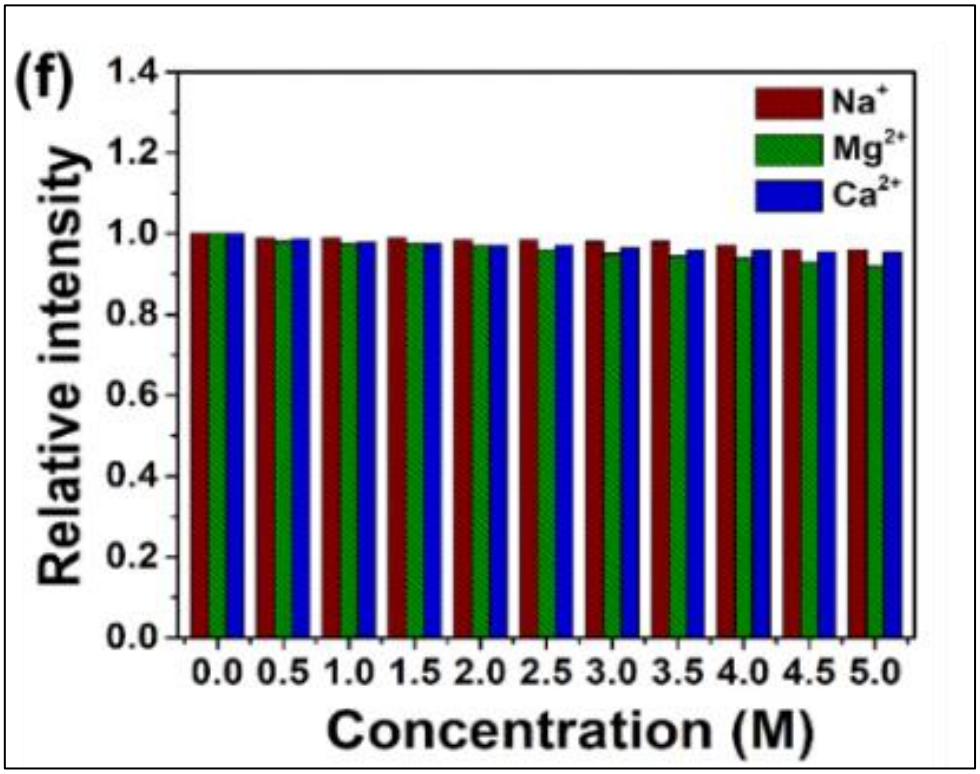


Figure 4.5 (f): Optical micrographs of GNSs.

4.2.2.4. Biocompatibility/toxicity measurements

The assessment of biocompatibility and cytotoxicity for fluorescent GNSs derived from chickpea sources was conducted through an examination to check their impact on cell lines, specifically focusing on their non-lethal effect. The evaluation included both the measurement of cell viability using the MTT enzyme assay and an analysis of the morphological characteristics of normal bronchial epithelial cells (BEAS-2B). A range of concentrations spanning from 10 to 50 µg/mL of the fluorescent GNSs was investigated (Figures 4.6(a) and 4.6(b)). The absence of toxicity observed in the MTT enzyme assay, even at higher concentrations of 25 and 50 µg/mL, signifies the non-harmful nature of the GNSs towards the BEAS-2B epithelial cells. This non-toxic response can be attributed to the specific characteristics of the GNSs, which promote their compatibility with the cellular components. The percentages of live/viable cells remaining above 95% at these elevated GNS concentrations further support the conclusion that the cells remained largely unaffected by the presence of the GNSs.

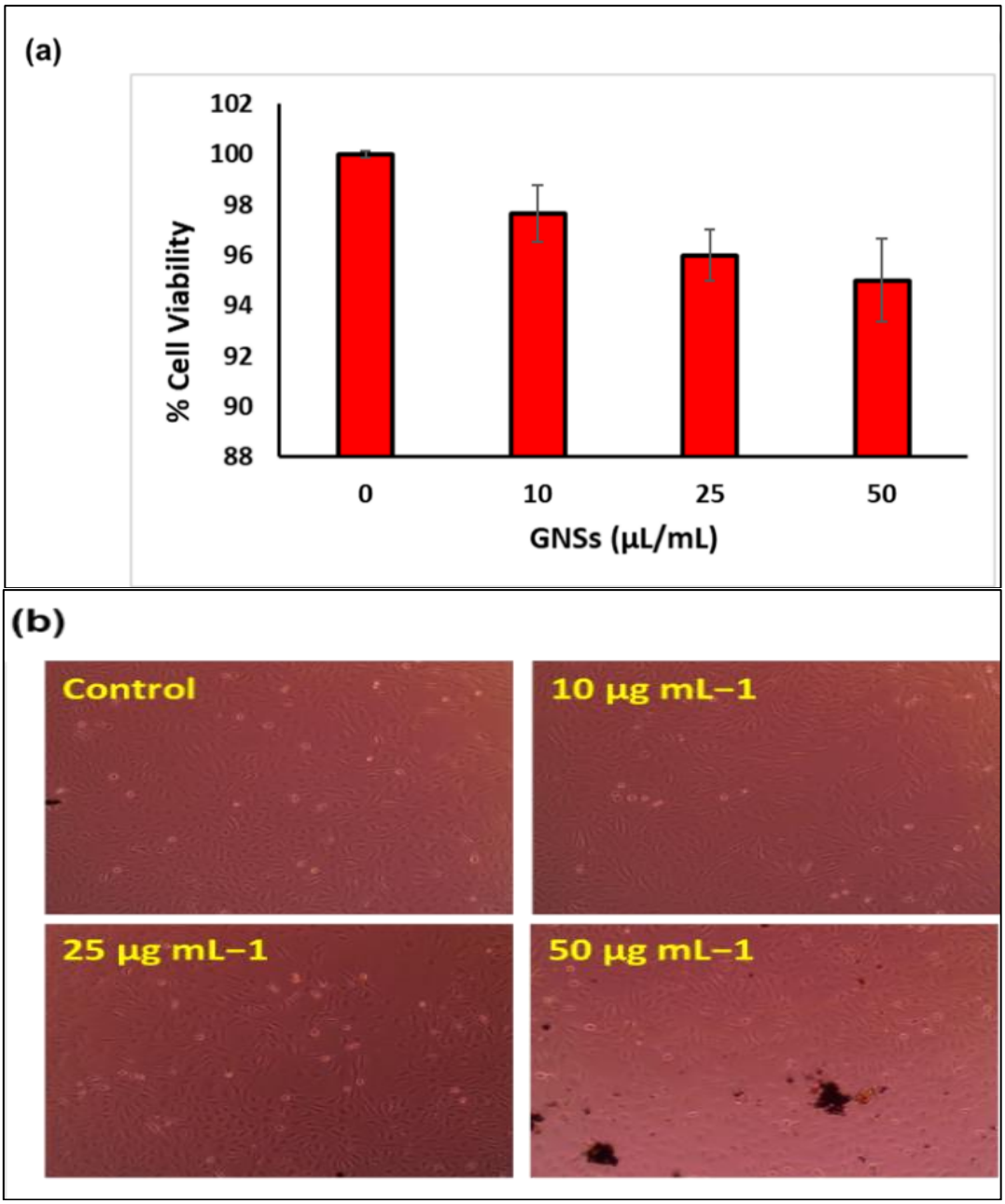


Figure 4.6: (a-b) Biocompatibility/ cytotoxicity of synthesized carbon nanodots (GNSs)

The negligible changes in the morphology of the treated BAES-2B cell lines were observed after exposure at high concentrations (25 and 50 µg/mL) compared to untreated cells (control). There was a deposition of the GNS matrix at the highest concentration (50 µg/mL); but it did not show any toxicity to the cells.

4.2.3. Antimicrobial spectrum of GNSs

4.2.3.1. Inhibitory effects of GNSs on B. cereus cell growth kinetics

In this conducted assay, GNSs displayed compelling inhibitory activity against *Bacillus cereus*. At an extremely low concentration of 10 µg/mL, GNSs suppressed colony growth following a 24-hours interaction period with a *B. cereus* concentration of 10^6 CFU/mL (Figure 4.7(a)). The distinctive qualities of GNSs and their interaction with *B. cereus* were responsible for the observed result. Due to the special characteristics of their surface and nanoscale structure, GNSs interacted strongly with bacterial cells. GNSs might have potentially interfered with the vital cellular functions when contacted with *B. cereus*, which hindered the growth and proliferating of the bacterium. The strong inhibitory impact that GNSs showed at the prescribed dose of 10 g/mL highlights the strength of their antibacterial potential. This result highlights GNSs capacity to control *B. cereus* colony growth even at extremely low concentrations. The bacterial killing kinetics of GNSs suggested a significant (p<0.001) time-dependent decrease in the viable count of *B. cereus* as compared to the control. As depicted in Figure 4.7, a sharp 2-fold (4.11 log CFU/mL) time-dependent reduction in viable cell count was observed after 60 min of GNSs treatment, and 3-fold inhibition was observed after 150 min of incubation (Figure 4.7(b)). Similarly, after 24 hours, complete inhibition of viable colonies was observed (Figure 4.7(a)). But the viable count remained almost static throughout the experimental period in untreated control cells.

4.2.3.2. Fluorescence staining

Acridine orange/ethidium bromide (AO/EB) fluorescence staining following GNS treatment of the tested pathogen *B. cereus* (10^6 CFU/mL) at the MIC (10 g/mL) was performed to evaluate the effect of GNSs on the pathogens viability. The intense crimson fluorescence, firmly demonstrated the inhibitory effects of GNSs on the *B. cereus* cells (Figure 4.10) which was used to illustrate their inhibitory actions. A bright green fluorescence that represents the living and undamaged status of the cells was produced by the selective staining of viable cells by AO. In contrast, EB enters cells with damaged membrane integrity and caused a bright red fluorescence to appear, signifying cell death. To ensure the reliability of the findings, each experiment was meticulously replicated three times independently and at least three different fields for every culture were examined under observation. This rigorous approach reinforces

the credibility of the results and underscores the robustness of the observed inhibitory effects of GNSs on *B. cereus* cells.

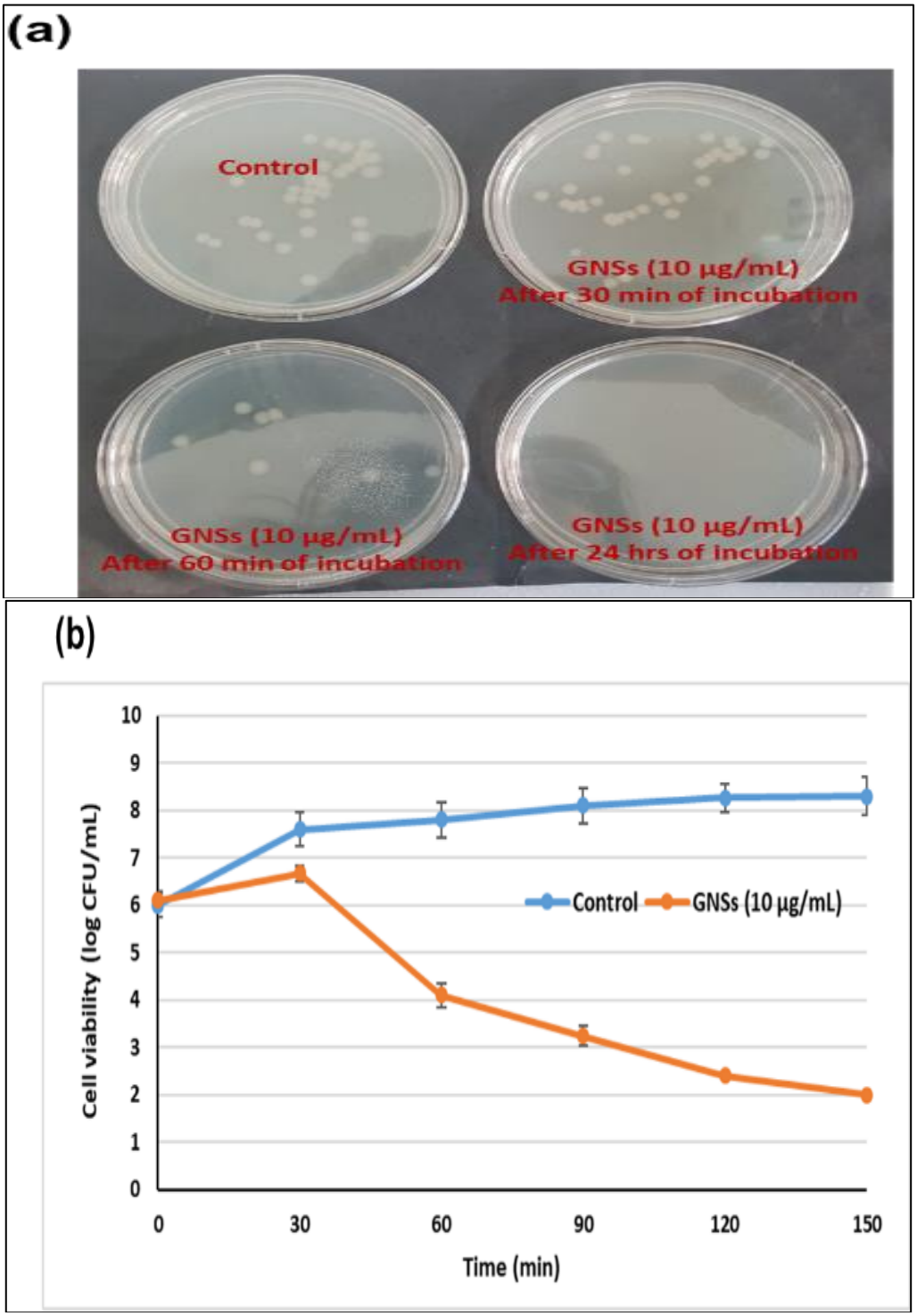


Figure 4.7: Anti-bacterial efficiency of as-synthesized GNSs. (a) viable cell counts after incubation of B. cereus (10^6 CFU/mL) with GNSs (10 µg/mL); (b) bacterial killing kinetics as per time-dependent activity.

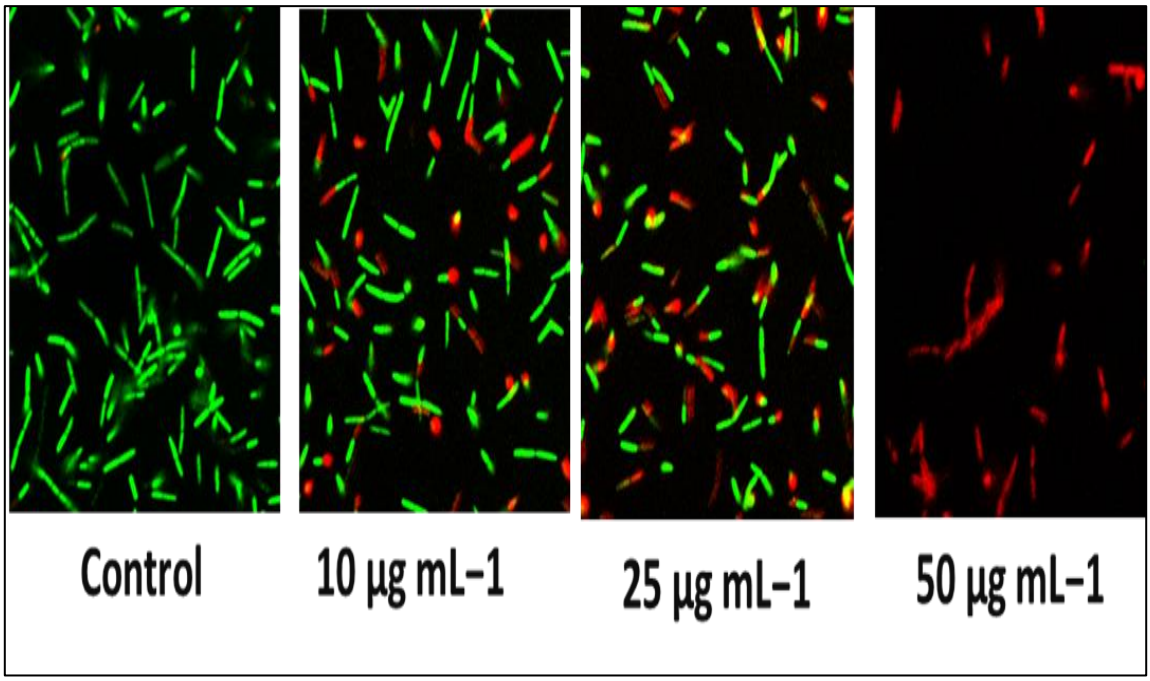


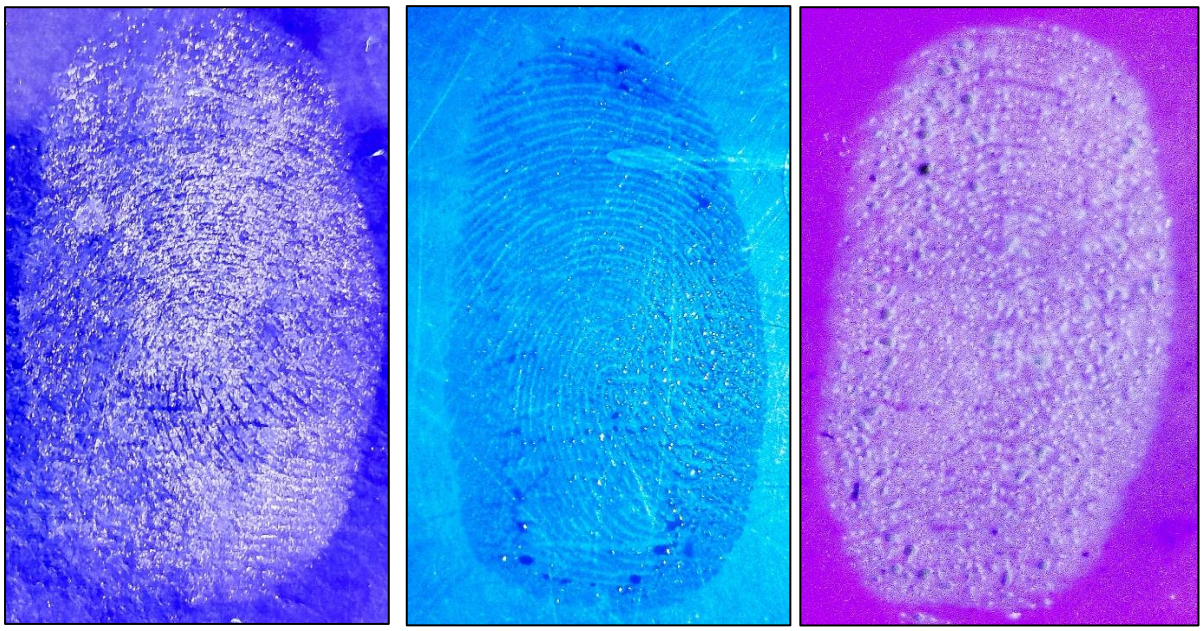
Figure 4.8: Live /dead cell population of B. cereus after treatment with GNSs.

4.2.4. Development of latent finger impressions using GNSs

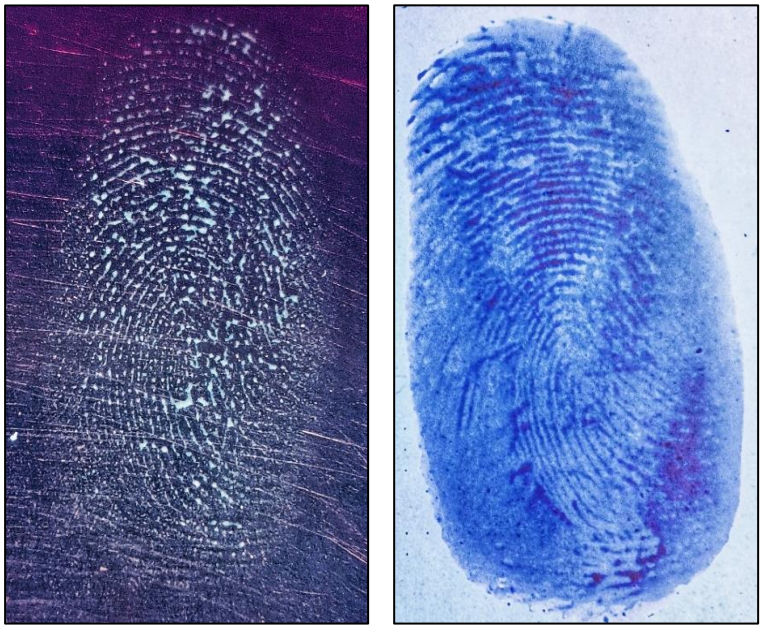
Among the techniques utilized, spraying or coating is a fundamental method to bond liquids with perspiration and oily substances present in fingerprint impressions, thereby enhancing the visibility of ridge patterns and individual characteristics. A unique and innovative approach employs Graphene Nanosheets (GNSs) for the development of quiescent finger impressions, capitalizing on their physical adsorption properties. The GNSs were employed to create dormant finger impressions on various surfaces, encompassing glass slides, paper, marble, steel plates, and plastic plates (Figure 4.9). The incorporation of GNSs was driven by their ability to adsorb onto the ridges formed during fingerprint imprinting and revealing the fingerprint pattern when subjected to 365 nm UV light, preserved by taking photographs in .jpeg format using OnePlus 8 mobile camera (48 megapixel). This method yielded varying outcomes based on the surface type.

For plastic, steel, and paper surfaces, the application of GNSs generated promising results (Figure 4.9 (b), (d), and (e)). The fingerprint residue on these surfaces remained suspended, resulting in vivid and well-defined fingerprint images. The ridge characteristics, including bifurcations, trifurcations, and other individual features, were notably distinct. Conversely, the application of GNSs on marble and glass surfaces produced noticeable fingerprint

patterns but compromised ridge clarity. The developed finger impressions exhibited multiple levels of details crucial for forensic analysis. Level 1 details encompassed the overall fingerprint pattern, aiding in identification and classification (Figure 4.10, 4.11). Meanwhile, level 2 details i.e., ridge characteristics were also clearly visible which are essential for individual identification (Figure 4.12, 4.13, 4.15). The GNS-enhanced impressions showcased level 3 details, such as sweat pores, which provide additional information for forensic examination (Figure 4.14). To enhance the clarity of the developed finger impressions, a black and white filter was applied, refining the visibility of ridge patterns (Figure 4.13). Hence, the utilization of Graphene Nanosheets for quiescent finger impression development introduces an innovative and effective approach in fingerprint analysis. This technique enhances the visibility of ridge patterns and individual characteristics, while the varying results based on substrate type further contribute to the complexity and potential of this method in forensic investigations.



A) Glass B) Plastic C) Marble



D) Steel E) Paper

Figure 4.9: Fingerprints developed on various surfaces (A) Glass, B) Plastic, C) Marble, D) Steel, E) Paper).

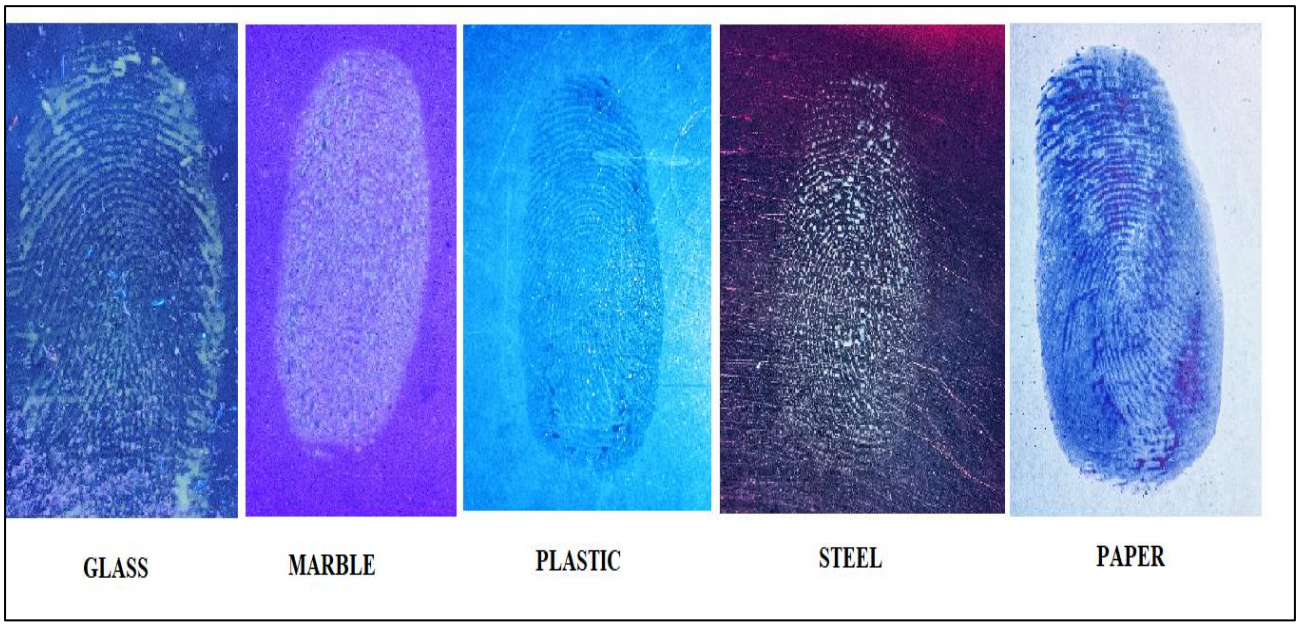


Figure 4.10: Developed fingerprints on various non-porous and porous surfaces using GNSs.

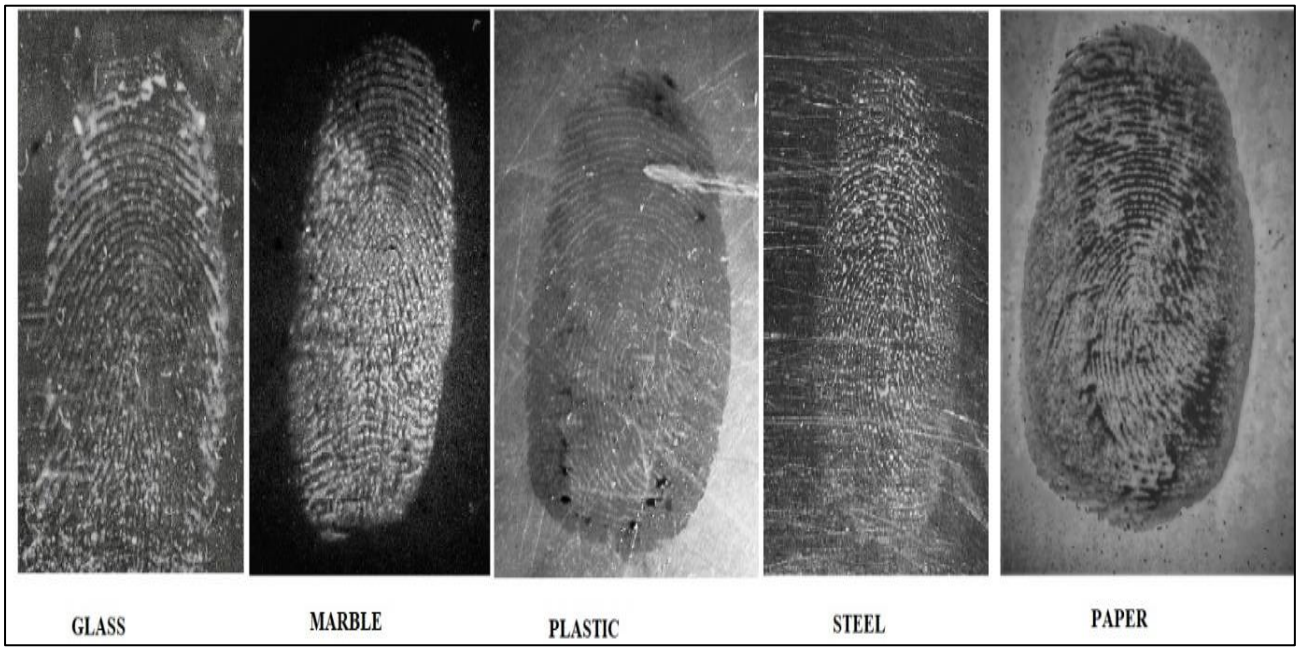


Figure 4.11: Developed fingerprints on various non-porous and porous surfaces using GNSs (with black and white filter).

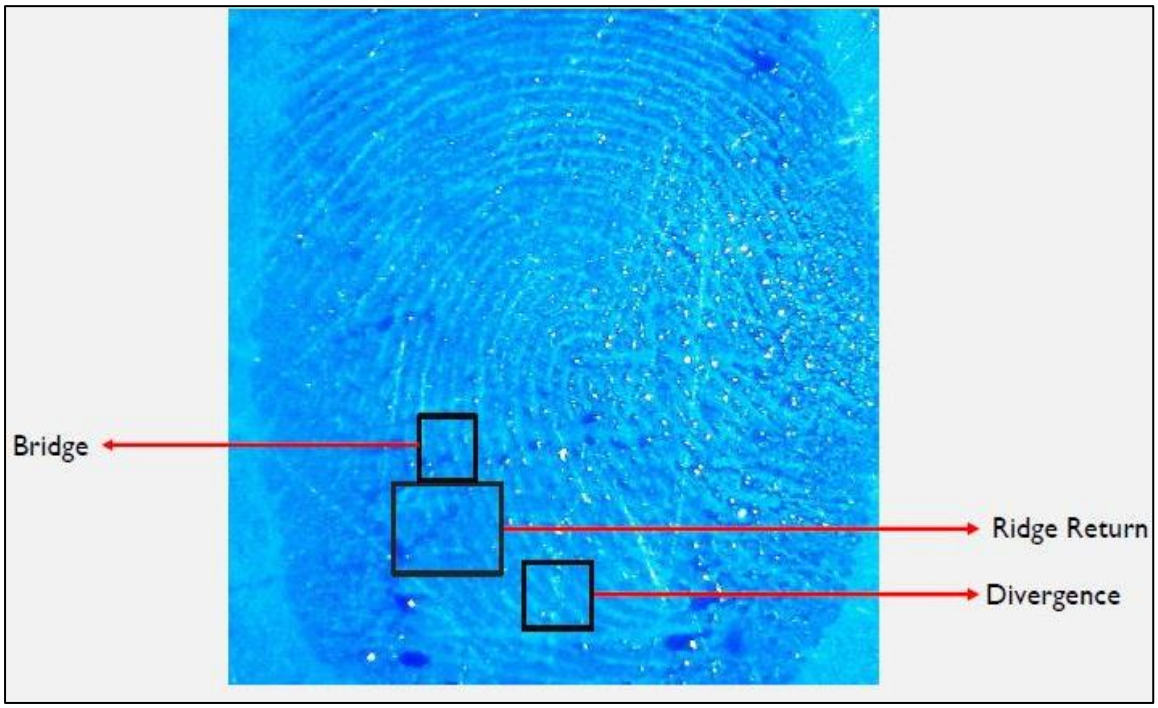


Figure 4.12: Visible individual characteristics on plastic surface showing bridge, ridge return, and divergence.

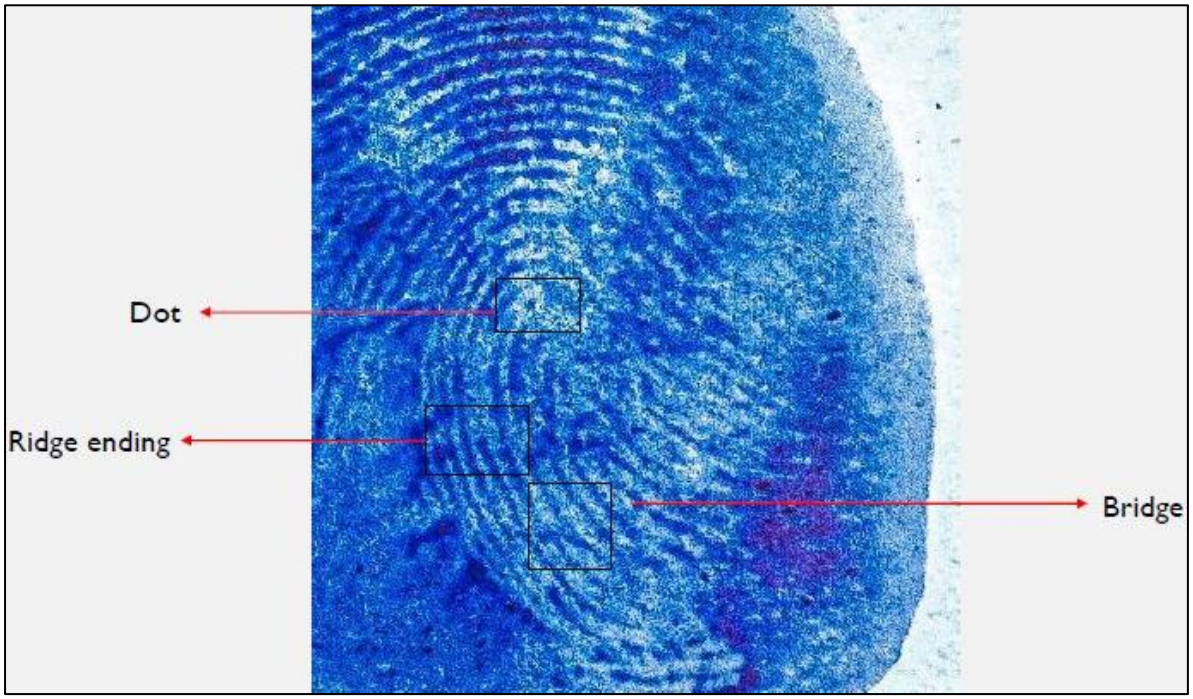


Figure 4.13: Visible individual characteristics on paper (porous surface) showing dot, bridge, and ridge ending.

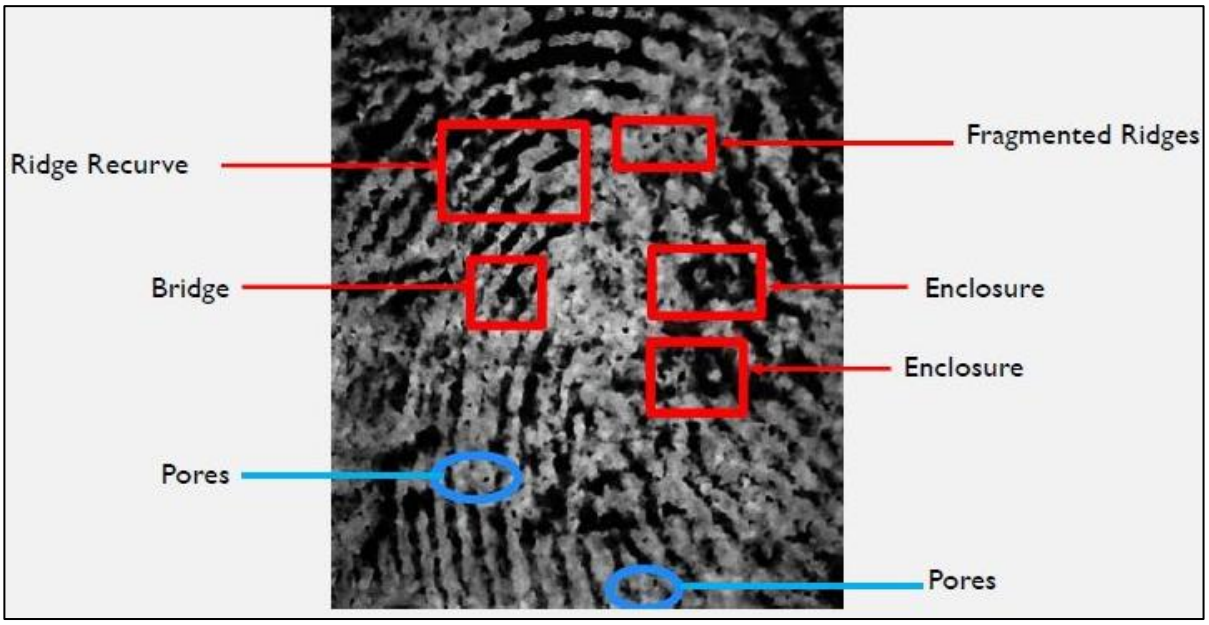


Figure 4.14: Visible individual characteristics on marble (non-porous surface) showing ridge recurve, fragmented ridges, enclosure, and bridge with level III characteristics.

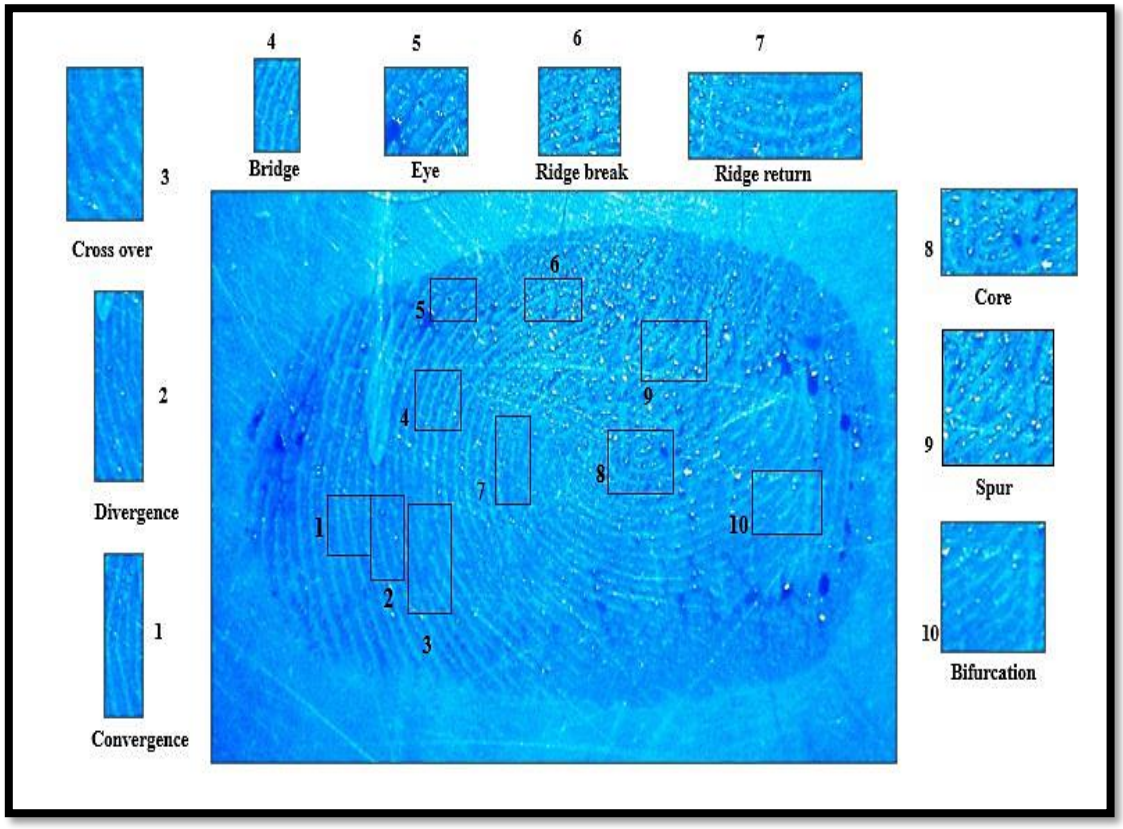
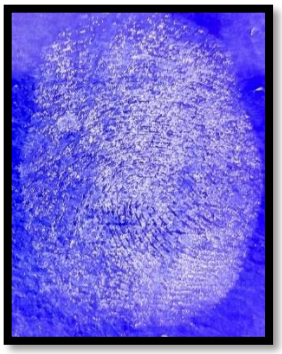
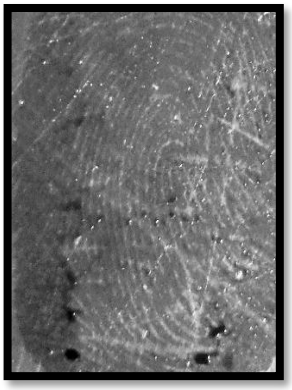
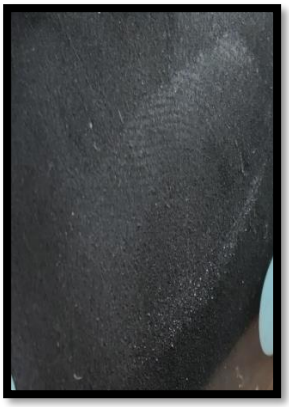


Figure 4.15: Visible individual characteristics on non-porous surface showing different ridge characteristics.

Table 4.1. **Comparison of developed latent finger impression under Normal light and UV Light.**

Surfaces	Under Normal Light	Under UV Light (365nm)	Black & White image
Glass Slide			
Marble Surface			
Plastic Surface			
Steel			

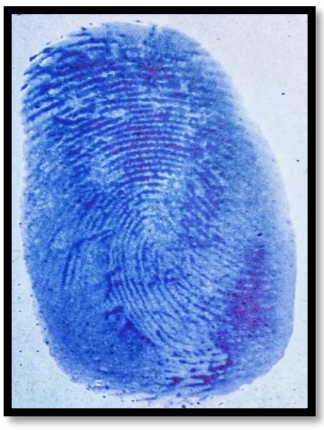
Paper			

Table 4.2. Latent finger impressions developed using GNSs.

S.No.	Surface	Material	Level-I (Pattern)	Level-II (Ridge characteristics)	Inference
1.	Non-porous	Glass Slide	Visible	Visible	GNSs developed latent fingerprints on non-porous surfaces with clear appearance of class and individual Whereas fingerprints are not developed on all porous surfaces.
2.	Non-porous	Marble Surface	Visible	Visible	
3.	Non-porous	Plastic Surface	Visible	Visible	
4.	Non-porous	Stainless Steel	Visible	Visible	
5.	Porous	Paper	Visible	Visible	

The GNSs can be used on porous and non-porous surfaces as they give distinct results on both surfaces. The GNSs developed hidden finger impressions on non-porous surfaces (plastic, marble, glass, and steel) and porous surface (paper) with a clear appearance of class and individual characteristics as well as pores (Figures 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15).

The outcome may be due to the reaction between carbon and the phosphate present in the sweat, as reported by (L. Yang *et al*., 2021). Similar studies have been conducted by several scientists to show the importance of carbon nanomaterials including carbon dots in the development of latent fingerprint impressions (Nugroho *et al*., 2022; Qu *et al*., 2012; Tang *et al*., 2019). On many non-porous surfaces like glass, metal, tiles, and porous surfaces like paper, the carbon quantum dots were found to provide clear and precise images of latent finger impressions with little background discoloration, exposing outstanding ridge characteristics. Using the synthesized carbon quantum dots nanoparticle liquid formation showed the excellent visibility of the minute details or ridges. A few other compositions of graphene nanomaterials and C dots were also investigated for such fingerprinting purposes by Chen *et al*., where researchers combined 1% Carbon dots with starch powder and discovered comparable encouraging outcomes for the fluorescence imaging of latent fingerprints on a variety of non-porous substrates (J. Chen *et al*., 2017).

Like the current research, (Nugroho *et al*., 2022) developed graphene / carbon dots from *Magnolia grandiflora* at various times (14, 16, 18, and 20 min) and further surface-functionalized with hydrogen sulfide (H_2S) to synthesize S-doped carbon quantum dots (CQDs). The synthesized S-doped CQDs had a uniform size according to TEM analysis, along with an amorphous structure, water solubility containing hydroxyl and carboxyl groups, excitation light-dependent characteristics, and high photostability. The synthesized S-doped-carbon nanomaterials have been used in latent fingerprint detection, and it is shown more clearly under UV lamp and has a bright blue fluorescence. This study used S-doped carbon/ graphene nano materials derived from natural resources as high-performance fluorescent probes for the detection of latent fingerprints on non-porous surface material (J. Chen *et al*., 2017; Tang *et al*., 2019).

In several studies, the graphene or carbon nanomaterials a particular class of semiconductor material that is generated by group II–VI binary compounds and has a nanoscale (2–20 nm) size in three dimensions have been utilized for fingerprint development. CdS, CdSe, and CdTe quantum dots (QDs) have been shaped for creating hidden fingerprints with high sensitivity and outstanding background contrast. The nature of cadmium is highly toxic which raises the major concern about using cadmium (Cd)-containing quantum dots (Haidong Li et al., 2021). Considering the toxic effects of fluorescent cadmium dots the biomass-generated graphene nano-sheets will facilitate environmentally friendly properties.

CHAPTER-5

CONCLUSION

5. CONCLUSION

In the current research work biocompatible MSNPs and waste biomass originated biocompatible fluorescent graphene nano-sheets have been developed that gives blue color under a UV torch (365nm). The application of the powdered silica nanomaterial was carried out with experiments on various non-porous materials (glass, plastic, silicon, steel, soft plastic, etc.) Therefore, these MSNPs can be applicative for identifying fingerprints on different surfaces. In case of GNSs, result was found on both porous and non-porous surfaces (plastic, marble, glass, steel, paper). Thus, widen the usage range of GNSs on various kind surfaces.

For the formation of hidden finger-impressions, the use of MSNPs and GNSs has several imperative advantages. These are sustainable and biocompatible in nature. By repurposing waste biomass, using chickpeas as precursor for the development of GNSs, these fluorescent graphene nano-sheets contribute to waste reduction and minimize the reliance on non-renewable resources. Additionally, the biocompatibility of these nano-sheets ensures their safe handling and application in enhancing the latent fingermarks. The MSNPs has a high surface area and a porous shape that promotes greater interaction with the proteins and amino acids found in latent fingerprints whereas, GNSs interacts with the organic components found in the latent impressions. This increased sensitivity results in better visualization and increased contrast of the ridge patterns, which facilitates accurate identification and analysis of latent fingerprints. The fingerprint residues can be identified with reliability and accuracy. Whereas the graphene nano-sheets are resistant to environmental factors, such as humidity and temperature variations, which allows for reliable fingerprint development and storage. These nanoparticles can be applied to a wide range of surfaces, including paper, glass, plastic, and metal, enabling effective latent fingerprint development across diverse crime scenes. They have low background interference, which reduces the presence of undesired signals or characteristics while developing a finger impression. Because of this quality, the fingerprint patterns are kept in the forefront, making it easier to see and understand the ridge intricacies. These nanoparticles are harmless to forensic experts, the environment, and other living things. Due to their biocompatibility, they may be handled safely, and any potential health hazards brought on by the usage of dangerous substances are eliminated. This also provides a comparatively cost-effective approach to latent fingerprint detection. By repurposing waste

materials, the production costs are reduced, making the technique more accessible for forensic laboratories and crime scene investigations.

The synthesis of nanoparticles using eco-friendly methods have shown a lot of potential to develop concealed fingerprints. These nanoparticles which are derived from natural sources have several advantages over traditional approaches, making them a possible replacement in forensic investigations. Their environmentally friendly nature, enhanced sensitivity, rapid processing, stability, and safety make them valuable tools in forensic investigations. Green synthesis approach for nanoparticles is based on the usage of green technologies and green materials and to minimize or diminish the usage of harmful chemicals involve in their synthesis thus reducing the environmental pollution. Current research involved the green synthesis of nanoparticles that were found as a potential candidate for latent fingerprinting with improves sensitivity, selectivity and detection. The stability and durability of green-synthesized nanoparticles also contribute to their effectiveness in the development of latent fingerprints. These nanoparticles have good storage stability and can endure a variety of environmental conditions, guaranteeing that fingerprint evidence may be maintained and examined for a long time. They relatively are safer for forensic experts and the environment due to their non-toxic nature than conventional metallic nanoparticles. The danger of exposure and potential health risks connected with conventional fingerprint generation processes are substantially reduced by eliminating toxic chemicals.

Biocompatibility, sustainability, fluorescence-based visualization, increased sensitivity and selectivity, stability, versatility, cost-effectiveness, minimal background interference, and safety are just a few advantages of using Mesoporous Silica nanoparticles and biocompatible fluorescent graphene nano-sheets made from waste biomass for latent fingerprint detection. By harnessing these advantages, forensic investigators can improve the efficiency and accuracy of latent fingerprint analysis, ultimately contributing to more effective crime scene investigations and the pursuit of justice.

FUTURE SCOPE

The application of green synthesized nanoparticles can be further enhanced for the hidden finger impressions by tailoring the particle size, pore structure, and functionalization strategies to improve the interaction with fingerprint residues, resulting in clearer and more distinct ridge patterns. This could also help in getting results on the porous surfaces. As these nanoparticles have given better results on the non-porous surfaces only. Hence, further study needs to be done to check the compatibility of mesoporous silica nanoparticles and graphene nanosheets on various porous surfaces.

Mesoporous silica nanoparticles and graphene nanosheets can be used in conjunction with other detection methods like fluorescence, raman spectroscopy, or electrochemical techniques to perform multimodal detection of latent fingerprints. The combination of various methodologies may offer further data and improve the overall precision and dependability of fingerprint analysis. To achieve higher resolution and more accurate imaging of latent fingerprints, advanced imaging techniques can be combined with green-synthesized nanoparticles and nanosheets, such as SEM, AFM, or super-resolution microscopy. These methods enable more accurate fingerprint identification and comparison by exposing finer ridge features.

The compatibility of green-synthesized MSNPs and GNSs with difficult surfaces, such as highly polluted or textured substrates, or wet surfaces as there are underwater crime scenes can be further study. These nanoparticles and nanosheets can be successfully used on a greater variety of evidence types by developing surface treatments or alterations, increasing their usefulness in forensic investigations.

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APPENDICES

CONSENT FORM

Consent Form

I, Mr./Miss/Mrs./Dr. _____, is convinced and have completely understood the research work which is being done by Ms. Kajol Bhati, Research Scholar, Forensic Science, Galgotias University, entitled “Green synthesis of nanoparticles and its application in latent fingerprints imaging”. I therefore, do not have any objection to give her my Fingerprint sample.

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Waste biomass originated biocompatible fluorescent graphene nano-sheets for latent fingerprints detection in versatile surfaces

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Abstract: In recent years; the application of biocompatible and non-toxic nanomaterials in the detection of fingerprints has become the major interest in the forensic sector and crime investigation. In this study; waste chickpea seeds; as a natural resource; were bioprocessed and utilized for the synthesis of non-toxic graphene nano-sheets (GNS) with high fluorescence. The graphene GNS were synthesized *via* pyrolysis at high temperatures and were characterized by TEM; XPS; fluorescence and UV-Vis spectroscopy; and FTIR analysis. The GNS exhibited excitation-independent emission at about 620 nm with a quantum yield of over 10%, and showed more distinct blue light under a UV lamp. Biocompatibility of the synthesized GNS in terms of cell viability (88.28% and 74.19%) was observed even at high concentrations (50 and 100 mg/mL); respectively. In addition; the antimicrobial property of the synthesized GNS-based coatings was also tested with a pathogenic strain of *Bacillus cereus* via live/dead cell counts and plate counting method; confirming their biocompatible and antimicrobial nature for their potential use in safe fingerprint detection. The developed chickpea-originated fluorescent GNS-based spray coatings were tested on different surfaces; including plastic; glass; silicon; steel; and soft plastic for the detection of crime scene fingerprints. Results confirmed that GNS can be used to detect latent fingerprints on multiple non-porous surfaces and were easy to detect under a UV lamp at 395 nm. These findings reinforce the suggestion that the developed fluorescent GNS spray coating has a high potential to increase sensitive and stable crime traces for forensic latent fingerprint detection on the nonporous surface material. Capitalizing on their color-tunable behavior; the developed chickpea-originated fluorescent GNS-based spray coating is ideal for the visual enhancement of latent fingerprints

Keywords: Finger impressions; fluorescent graphene nano-sheets; biomass generated; antimicrobial; non-toxic

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1. Introduction

Fingerprint analysis, also known as dactyloscopy, is by far the most popular identification technique and has been utilized extensively in police prosecutions for more than a decade. The fingerprint is the main evidence in forensic science because each person has

a distinct pattern of epidermal ridges on their fingers hence, no two entities have the same type of fingerprints. When a person touches any kind of solid surface leads to the transfer of natural skin secretions and exogenous residues present on their fingers to those surfaces. This transfer forms the finger impression on the surface [1]. Ridge patterns that have been electronically or manually recorded are kept in national archives so that impressions discovered at crime scenes can be automatically compared to the police database [2]. The exploitation of fingerprints to identify the crime, criminals and victims, is as old as it has been used as a seal on documents, for the identification of the artist who made the painting or pottery, and as advanced as it has become part of the organization for biometric application which are quickly gaining acceptance in commonplace applications ranging from access control to digital authentication for electronic devices to homeland security [3–5].

The identification of finger impressions has played a major part in criminal investigations, due to its uniqueness. Latent prints present at the crime scene need attention and detection methods [6]. Early techniques based on ninhydrin, silver nitrate, iodine vapor, cyanoacrylate deposition, and vacuum metal deposition have been successful and are still being used in forensic labs to create latent fingerprints. When it comes to fingerprint dusting at crime scenes, materials based on aluminium, silica, titanium dioxide, and magnetic particles have been employed for decades [7]. These methodologies have several limitations in that not all levels of fingerprints have been established, they are poisonous, have strong autofluorescence incursion, interact with the background, and have indistinct ridges. Such limitations in conventional materials demand a novel, sustainable, and less toxic method to develop the fingerprints, which increase the accuracy of hidden finger impressions, lower their cost, and increase their effectiveness in assisting with investigations by identifying the offender [8,9].

Nanoscience has offered a sustainable solution and provided nanomaterials as a potential tool for the development of dormant finger impressions which helps in the personal identification and characterization of suspects and criminals who are connected to one another or the crime scene [7]. A few of the advantages of nanoparticles are high sensitivity, low toxicity, and high contrast pictures, some of which are also economically advantageous. Nanoparticles can physically bond by chemically interacting with the amino acids, fatty acids, and other water-soluble substances present in the impression [10]. Additionally, photoluminescence properties are present in nanomaterials. To enhance the hidden finger marks, scientists utilize nanoparticles made of gold, silver, titanium dioxide, zinc oxide, silica, etc. These nanoparticles have given better results than the conventional methods as they develop class, individual characteristics as well as the pores present in fingerprints [11].

In recent years, graphene sheets and other carbon based nano materials have gained importance due to the specificity of zero-dimensional carbon materials consisting of sp2/sp3 hybridized carbon atoms in the core with abundant functional groups on the shell and exhibited composition-dependent fluorescence properties. Graphene based materials trigger great concern in a wide range of applications ranging from bio-imaging, sensing, drug-delivery, photocatalysis, energy storage, and fluorescent ink to disease diagnosis due to their unique properties such as robust chemical inertness, non-toxicity, extreme biocompatibility, and great stability without photobleaching. However, low fluorescent quantum yield demands subsequent strategies, including functionalization or surface passivation to enhance the optical properties of GNS. Currently, heteroatom-doped graphene nano-materials are a hotspot, which provides a feasible and facile way to tune their intrinsic properties to achieve new and multifunctional applications. In this line of interest, a few researchers have explored the applications of grapnene based nano materials in fingerprinting applications.

GNS have a strong adherence to fingerprint residues as well as high-resolution imaging and improved visibility. Due to their robust photoluminescence, simple synthesis, simple surface functionalization, great chemical stability, and good water solubility, graphene nano-sheets (GNS) have garnered a lot of interest. Due to their lack of metals, GNS

also exhibit comparatively low toxicity and superior biocompatibility when compared to conventional organic dyes and semiconductor quantum dots. Graphene nano-sheets and other graphene based nanomaterials have been used extensively in energy conversion, optical sensing, and imaging systems [12]. The key to graphene-based compositions' ability to recover fingerprints is their capacity to change color when exposed by various light sources, allowing for background-free photos and maximizing the accuracy of fingerprint analysis. The use of a diluent matrix, the creation of core-shell nanostructures, the incorporation of heteroatom doping, the utilization of effects like resonance energy transfer and interactions, the use of molecular spacers, and other techniques have all been suggested to combat the tendency of graphene or other carbon based nano-materials in the solid state to self-quench [13,14]. Fernandes et al. were the first to demonstrate the use of carbon nanomaterials-based powders for fluorescent visualization of dormant finger impressions. They showed that the incorporation of 0.7 wt.% carbon nanomaterials into a silica matrix allowed a highly detailed and color-tunable visual display of dormant finger impressions on a glass slide as well as on a multicolor soft drink label [15,16].

The nanometer-sized GNS, which have minimal toxicity, biocompatibility, and water solubility, are a subset of the nanomaterial class. Several applications, including bioimaging, drug delivery, gene transfer, metal ion detection, sensing, and nanothermometer, can make use of the photoluminescence property of graphene and other carbon nano materials [17]. Many studies have shown that the carbon dots (CD) with liquid formulations display better visualization of hidden finger impressions. The colloidal stability of CD's dispersions in a variety of liquid media suggests that CD-based sprays give effective results [18,19]. Although attempts have been made to increase the detection limit of latent fingerprints (LFPs) by using fluorescent nanomaterials such as graphene nano-sheets, quantum dots, carbon dots, and up-conversion nanoparticles, issues still persist due to their poor detection performance, difficult manufacturing process, photobleaching, and toxicity. There is a need to develop more efficient and cost-effective graphene nanomaterials using easy methods. Therefore, in this study, to overcome the aforementioned limitations, this approach has been attempted to develop biomass-originated graphere nanosheets with no toxicity and antimicrobial efficiency for their further potential application in the detection of latent finger impressions.

2. Materials and Methods

2.1. Chemicals and reagents

All laboratory-grade reagents were acquired from commercial suppliers and used without any further processing or purification. Hydrochloric acid (HCl), methanol, ethyl acetate, mercuric chloride, and ethanol were of analytical grade (AR), and purchased from Merck (Mumbai, India). Millipore water (18.2 MΩ cm at 25 °C) was used for the preparation of all aqueous solutions. Whatman® Grade 1 filter paper, were purchased from Sigma-Aldrich (St. Louis, MO, USA).

2.2. Sample collection

The specimens for this study were given by selected people (2 female and 2 male). Each participant was instructed to wash the hands with soap and water. After which the fingers were placed on various surfaces (Both porous and non-porous surfaces). Each participant's full and incomplete fingerprints were obtained on these surfaces.

2.3. Synthesis of graphene nano-sheets (GNS)

Water soluble graphene nano-sheets (GNS) were synthesized using chickpeas as a precursor following the pyrolysis technique described earlier with some modifications [4]. Briefly, 2 g of powdered chickpea sample was put in a capped quartz boat and heated at 800°C for 2 h at a heating rate of 5º min^{-1} under an inert environment. Such synthesized soot was collected and treated with nitric acid to introduce hydrophilic groups. Typically,

1 g of soot was taken in 100 mL nitric acid (60%) and reflux for 12 h. The supernatant was collected *via* centrifugation and evaporated at a water bath until a slurry was formed. Afterward, 500 mL water was added to it and evaporated, this process was repeated to remove excess acid. When pH reached 7.0, the slurry was dried at room temperature and GNS were collected (Yield 60%).

2.4. Characterization of synthesized GNS

The microstructure and morphology of as-synthesized GNSs were characterized by TEM and HR-TEM (FEI Tecnai F30, operated at 300 kV). Optical absorption of GNSs was collected in an aqueous solution by a Varian 50 Bio UV-vis spectrophotometer. Emission spectra of GNSs were collected with a Varian fluorescence spectrometer in an aqueous solution at room temperature. Photoluminescence (PL) images of the aqueous solution of GNSs were acquired by a Leica inverted optical microscope (Leica DM 2500, Leica Microsystems Ltd.) on a glass plate. FTIR was performed with a Bruker Vector 22 spectrometer.

2.5. Cell lines experiments for cytotoxicity and morphological evaluation of GNSs

Bronchial epithelium cells (BEAS-2B) were cultured in RPMI-1640 media, supplemented with 10% (v/v) fetal calf serum and 1% penicillin–streptomycin cocktail at 37°C in a 5% CO_2 incubator. The cytotoxic effect of GNSs was first determined by MTT assay. Briefly, 6×10^4 BEAS-2B cells per well were incubated in the presence of various concentrations of GNSs (5–50 μL/mL) at 37°C in a CO_2 incubator for 24 h. After incubation, cells were treated with pre-developed MTT solution (5 mg/mL) to produce dark blue-colored formazan crystals, dissolved in 50 μL of dimethyl sulfoxide (DMSO). Finally, absorbance at 540 nm was measured using a multi-microplate reader.

2.6. Bacterial strain and antibacterial efficiency of GNSs

A food-hazardous pathogen *Bacillus cereus* was used as the target pathogen in the present study. It was grown in Luria–Bertani (LB) medium (Acumedia, Lansing, MI, USA) at 37°C and maintained on LB agar at 4°C. To reactivate the strain, the culture was taken out, and a loop full of cells was inoculated into fresh LB medium followed by incubation at 37°C for 24 h. All sub-cultures were maintained in the LB medium. In all experiments, phosphate-buffered saline (PBS) was used as a negative control.

2.6.1. Antibacterial and bacteria-killing kinetics of GNSs

To determine the antibacterial activity, the synthesized GNSs were prepared in different concentrations in LB broth ranging between 0–50 μg/mL. Finally, an inoculum of the mid-log phase of *B. cereus* (10^6 cells/mL) was added to each dilution and incubated at 37°C. After 24 h, the concentration GNSs that led to no visible growth was considered to be the effective concentration to kill the bacterial population. In order to confirm the visual growth reduction, the colony counting assay was performed in LB agar media *via* the pour plating method.

The time-dependent mortality of *B. cereus* in the presence of GNSs was also assessed. Briefly, tubes containing LB broth with GNSs at effective concentration were inoculated with bacterial cells (10^6 cells) and incubated at 37°C. At different time points (0, 30, 60, 90, and 120 min), 100 μL of the culture was withdrawn, serially diluted, and spread onto LB agar plates. Viability was assayed by counting the cells on the LB plates after incubation at 37°C for 24 h. Similarly, control tubes containing bacterium without GNSs were set up under the same experimental conditions, and the experiment was performed using three replicates.

2.6.2. Fluorescence microscopy staining assays for live/dead bacterial cells

The numbers of live and dead cells were evaluated using acridine orange/ethidium bromide (AO/EB) fluorescent staining. *B. cereus* cells (10^6 cells/mL) grown overnight were treated with or without GNSs (at MIC and 2×MIC) for 60 min at 37°C (based on pre-optimized conditions). After incubation, the cells were harvested using centrifugation, washed with PBS, and stained with Live/Dead ® BacLightTM Bacterial Viability Kit L13152 for 15 min in the dark. After incubation, the cells were washed with PBS, and images were obtained using confocal laser scanning microscopy, which were then processed with a Zeiss LSM Image Examiner (Version 4.2.0.121). All experiments were repeated three times independently, and at least three different fields were observed for each culture.

2.7. Application of GNSs for detection of fingerprints

For the purpose of assessing felonies, the synthesized GNSs were evaluated for their capacity to detect finger impressions on various surfaces (porous, semi-porous, and non-porous). In brief, a hairbrush was used to apply the GNSs nano-powder to the different surfaces. The substances secreted by the sebaceous, eccrine, and apocrine glands that result in a finger impression were being left on the surface. To develop the prints on the surface, hairbrush strokes were applied. The fluids were discovered in finger impressions were on the surface after wiping fingertips across the nose and forehead.

By using a hairbrush, nano-powder of GNSs was dispersed to the multiple substrates that retained latent finger impressions. The white color of the nano-powder contrasted well with both colored and dark surfaces. The latent fingermarks developed using nano-powder produced ridge features with little background disturbance.

3. Results

3.1. Synthesis and characterization of the synthesized GNSs

The pyrolysis of chickpea was performed at 9000°C for 2 h which yielded a black powder as shown in **Figure 1**. Further, the water solubility of as-synthesized GNSs was achieved by mild acid treatment with concentrated nitric acid. Oxidation endows GNSs with high-density negative surface functionalities along with PL properties.

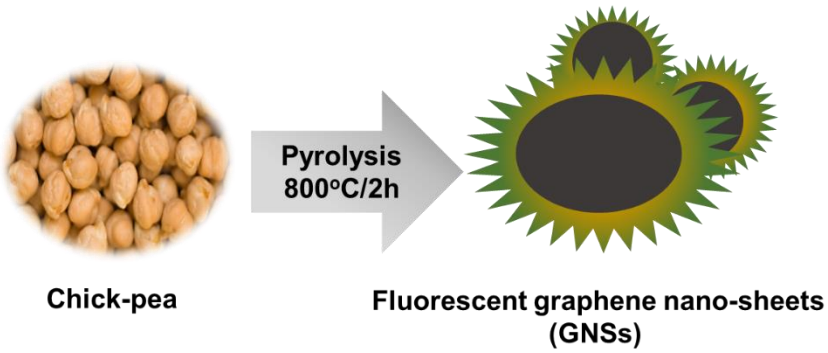

Figure 1. Brief representation for the synthesis of chickpea-originated fluorescent GNSs.

3.2. Characterization of GNSs

3.2.1. Morphological characterization

The morphology of GNSs was characterized by transmission electron microscopy (TEM) and high-resolution (HR)-TEM analysis. The typical TEM image in **Figure 2a** shows the spherical nature of GNSs without any other morphological impurities. GNSs are in the size range of 10-50 nm as calculated statically **(Figure 2b)**. The HR-TEM image in **Figure 2c** shows the graphitic nature of GNSs. The distance between two adjacent lattice fringes is 0.31 nm ascribed to a good degree of graphitization by Das et al., 2020 [19].

3.2.2. Structural characterization

Surficial functional groups of GNSs were identified with Fourier transform-infrared (FT-IR) spectroscopy. The development of π conjugated structure was confirmed by the existence of aromatic C=C vibrations peak centered at 1609 cm^{-1} and in-plane bending vibrations of aromatic C-H at 563 cm^{-1}. The broad band at 3435 cm^{-1} was assigned to the stretching vibrations of O-H. The peaks at 2917 cm^{-1} and 2851 cm^{-1} are ascribed to the aliphatic C-H stretching and the merged peak centered at 1726 cm^{-1} is attributed to C=O stretching. The band at 573 cm^{-1} corresponds to bending vibrations of =C-H. Peaks at 1120 cm^{-1} and 1039 cm^{-1} are ascribed to C-O and C-C stretching vibrations. The FTIR spectrum revealed the co-existence of the high density of oxygenous functional groups enables better stabilization of GNSs in water. The surface functional moieties of GNSs were further verified with X-ray photoelectron spectroscopy (XPS). **Figure 2d** presents the survey scan XPS spectrum of GNSs and confirms the existence of C and O elements with a composition of XX% and XX %, respectively. **Figure 2e** shows that the deconvolution of the C 1s signals results in five peaks at ~ 283.6 eV, 284.6 eV, 285.3 eV, 286.8 eV, and 287.6 eV corresponding to C=C, C-C, C-O, C=O and COO^- binding modes of carbon, respectively. **Figure 2f** shows the well-deconvoluted high-resolution spectra of O 1s with three peaks, where the peak at ~530.7 eV is associated with C-O and peaks at 531.8 eV and 534 are ascribed to C=O and COO^-, respectively.

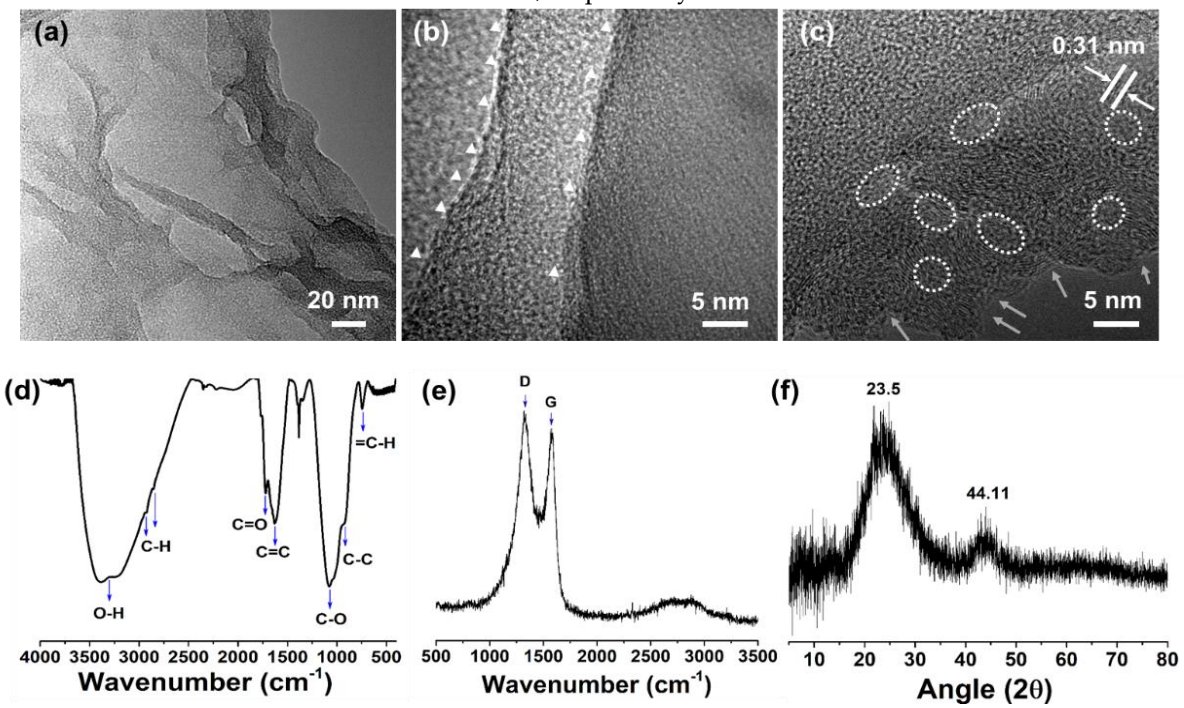

Figure 2. (a) Low-resolution TEM image of GNSs; **(b)** high-resolution TEM image of GNSs; **(c)** HR-TEM image of GNSs showing interlayer spacing; **(d)** FTIR spectrum of GNSs; **(e)** Raman spectrum of GNSs; **(f)** XRD spectrum of GNSs.

3.2.3. Optical characterization

The Uv-vis absorption spectrum of GNSs as shown in **Figure 3a**, shows an evident absorption band at ~ 200 nm with a continuous tail through the entire visible region, ascribed to π-π^* and n-n^* transitions of conjugated C=C and C=O. The absence of any background absorption indicates that there is no other morphological impurity. The PL spectra in **Figure 3b** indicate typical excitation-independent emission spectra ranging from 360 to 620 nm excitation wavelengths at a continuous increment of 20 nm. The maximum emission was centered at ~ 708 nm, while the maximum emission intensity was observed at ~475 nm. Excitation wavelength-dependent emissions of GNSs attributed to the different photon absorption mechanisms.

The quantum yield of GNSs was measured to be 22 % with reference to quinine sulfate, indicating the strong quantum confinement of particles. The optical properties of

GNSs were also investigated under the continuous irradiation of high intensity UV light and in the presence of high ionic strengths. The emission intensity centered at 475 nm remains almost similar after 1 hour's continuous irradiation of UV light. No perceptible changes in PL emission intensity were observed under the influence of high ionic strength (0.5 M to 3.5 M) with Na^+, K^+, Ca^{2+}, and Mg^{2+} as shown in **Figure 3d**. GNSs exhibited good photostability without any change in visual appearance after several months when stored in a closed vessel at room temperature. Hence, GNSs could be a potential PL probe at various physical salt concentrations. The green and red fluorescence optical micrographs as shown in **Figures 3e** and **3f,** respectively under different band-pass filters, reveal the highly florescence nature of GNSs.

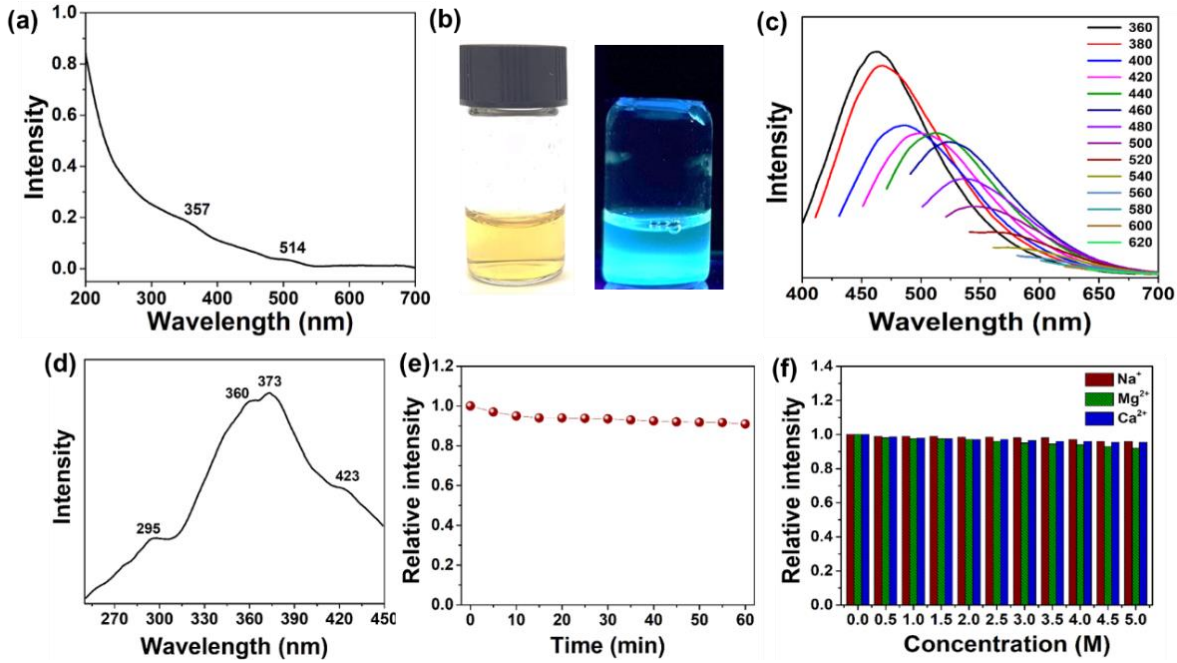

Figure 3. (a) UV-Vis absorption spectrum of GNSs; **(b)** synthesized fluorescence nanostructures of GNSs under UV lamp; **(c)** emission spectra of GNSs excited by different wavelengths. Photostability test of GNSs; **(d)** at continuous irradiation of UV light (e) under continuous UV light (365 nm) irradiation and **(e)** in the presence of high ionic strength of Na^+, K^+, Ca^{2+}, and Mg^{2+}. **(f)** Optical micrographs of GNSs.

3.3. Biocompatibility / toxicity measurements

The biocompatibility and cytotoxicity of the chickpea-originated fluorescent GNSs were examined by observing their non-killing effect on cell lines and resulting in the cell viability measurements *via* MTT enzyme assay, and cellular morphological characteristics of normal bronchial epithelial cells (BEAS-2B). Different concentrations of fluorescent GNSs ranging from 10 to 50 µg/mL showed no toxicity on BAES-2B epithelial cells when tested with MTT enzyme assay (**Figures 4a** and **4b**). Briefly, the percentages of live/viable cells at higher concentrations of the GNSs i.e., 25 and 50 µg/mL were observed above 95% (**Figure 4**). Also, negligible changes in the morphology of the treated BAES-2B cell lines were observed after exposure at high concentrations (25 and 50 µg/mL) compared to untreated cells (control). Interestingly, it has been observed that at the highest concentration (50 µg/mL), there was a deposition of the GNS matrix; however, it did not show any toxicity to the cells.

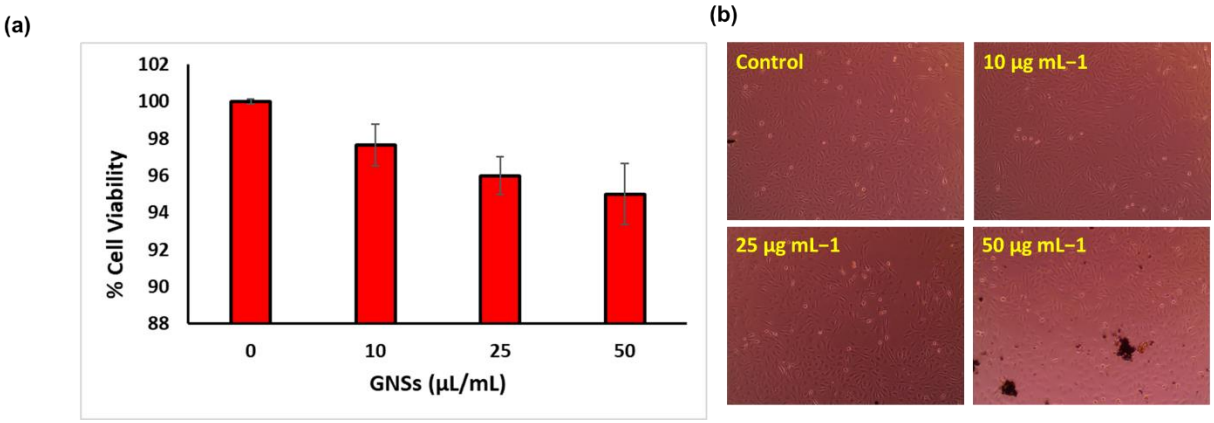

Figure 4. Biocompatibility/ cytotoxicity of synthesized carbon nanodots (GNSs).

3.4. Antimicrobial spectrum of GNSs

3.4.1. Inhibitory effects of GNSs on B. cereus cell growth kinetics

In this assay, GNSs demonstrated strong inhibitory activity against *B. cereus* in the form of no colony growth with a minimal concentration of 10 µg/mL after 24 h of the interaction of *B. cereus* (10^6 CFU/mL) (**Figure 5a**). The bacterial killing kinetics of GNSs suggests a significant (p<0.001) time-dependent decrease in the viable count of *B. cereus* as compared to the control. As depicted in **Figure 5**, a sharp 2-fold (4.11 log CFU/mL) time-dependent reduction in viable cell count was observed after 60 min of GNSs treatment, and 3-fold inhibition was observed after 150 min of incubation (**Figure 5b**). Similarly, after 24 h, complete inhibition of viable colonies was observed (**Figure 5a**). On the other hand, the viable count remained almost static throughout the experimental period in untreated control cells.

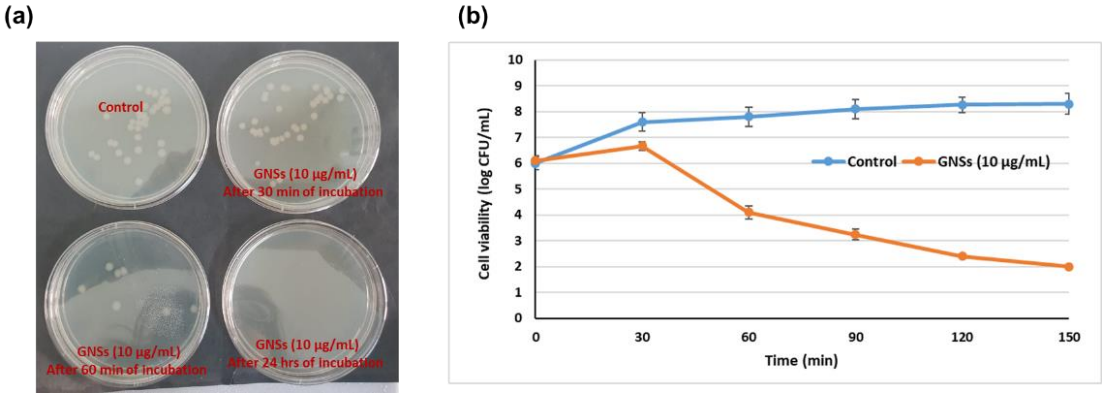

Figure 5. Anti-bacterial efficiency of as-synthesized GNSs. **(a)** viable cell counts after incubation of *B. cereus* (10^6 CFU/mL) with GNSs (10 µg/mL); **(b)** bacterial killing kinetics as per time-dependent activity.

3.4.2. Fluorescence staining

Acridine orange/ethidium bromide (AO/EB) fluorescence staining was performed after treatment of the tested pathogen *B. cereus* (10^6 CFU/mL) at the MIC (10 µg/mL) of GNSs. The inhibitory effects of GNSs were confirmed by the presence of highly red-colored fluorescence, thereby confirming their toxicity to cells of the tested pathogen *B. cereus* (**Figure 6**). Generally, in AO/EB staining, AO stains live cells while EB stains cells that have lost their membrane integrity. AO-stained cells give green fluorescence representing live cells while EB gives red fluorescence denoting dead cells. All experiments were repeated three times independently and at least three different fields were observed for each culture.

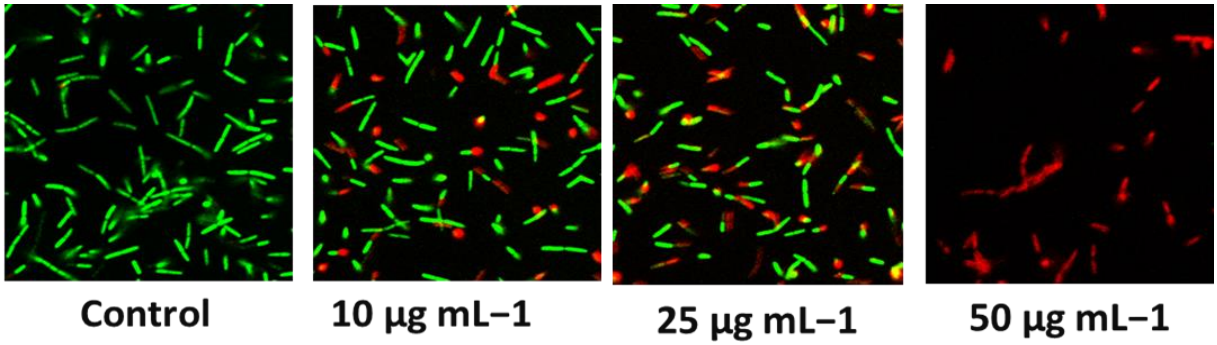

Figure 6. Live /dead cell population of *B. cereus* after treatment with GNSs.

Table 1. Latent finger impressions developed using GNSs.

S.No.	Nanoparticles	Surface	Material	Level-I (Pattern)	Level-II (Ridge characteristics)
1.	GNSs	NON-POROUS	Glass Slide	Visible	Visible
2.	GNSs	NON-POROUS	Marble Surface	Visible	Visible
3.	GNSs	NON-POROUS	Plastic Surface	Visible	Visible
4.	GNSs	NON-POROUS	Stainless Steel	Visible	Visible
5.	GNSs	POROUS	Paper	Visible	Visible

3.5. Development of quiescent finger impressions using GNSs

Spraying or coating is a basic physical technique to bond the liquid to perspiration and greasy materials like oil and grease in the fingerprint impression. Due to the presence of perspiration and oil in the fingerprint residue, GNSs were physically adsorbed into the ridges made on the surface during imprinting at a better level. The fingerprint pattern was then revealed once more when the fluorescent GNSs in the fingerprints were subjected to 365 nm UV light.

3.6. Development of latent fingerprints by using the GNSs

The dormant finger impressions were developed on five different porous and non-porous surfaces, including glass slide, paper, marble, steel plate, and plastic plate using GNSs (**Table 1**). The GNSs showed good results on plastic, steel, and paper surfaces as the finger-mark residue remains suspended on the surface (**Figure 7**). It gave the clear image of a fingerprint with a distinct clarity of ridge characteristics. Whereas the prints developed on the marble and glass surface showed the fingerprint pattern but the ridge characteristics were not clear (**Figure 7**). The developed finger impressions showed level 1 (pattern) and level 2 details (individual characteristics - bifurcation, trifurcation, dot etc.) (**Figures 9, 10, and 11**). Whereas level 3 (sweat pores) details were also visible in it (**Figure 11**). A black and white filter was applied to get a clear image and detailed ridges (**Figure 8**).

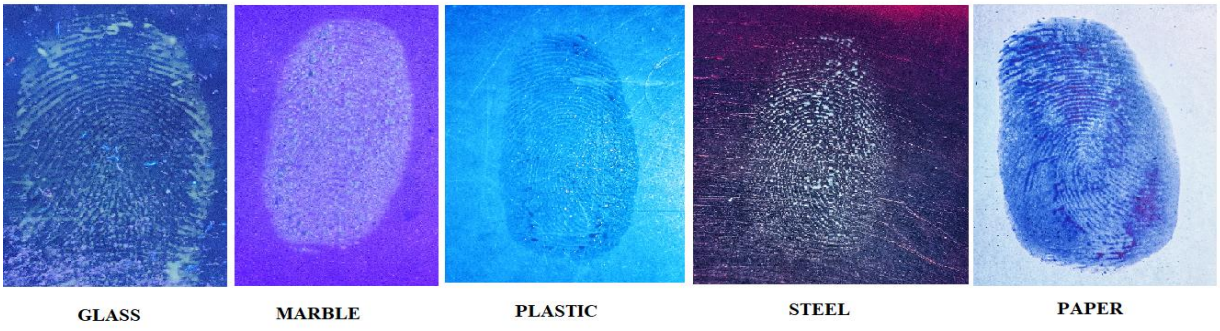

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Figure 7. Developed fingerprints on various non-porous and porous surfaces using GNSs. 345

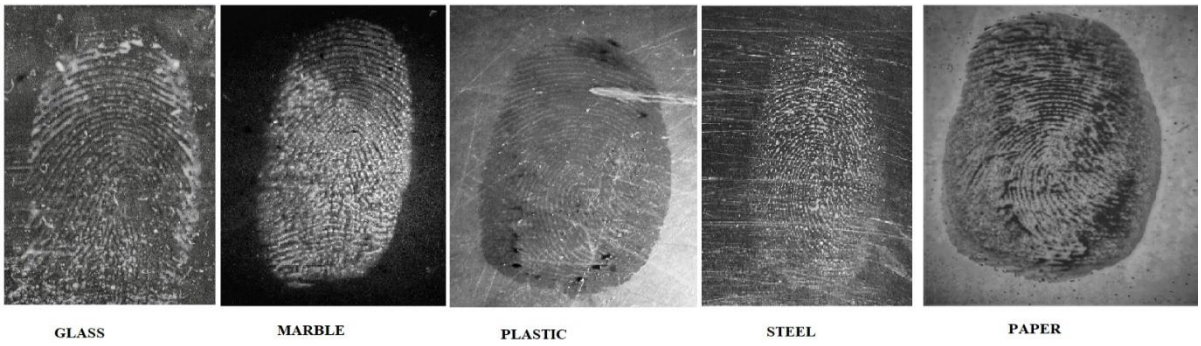

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Figure 8. Developed fingerprints on various non-porous and porous surfaces using GNSs (with black and white filter). 347 348

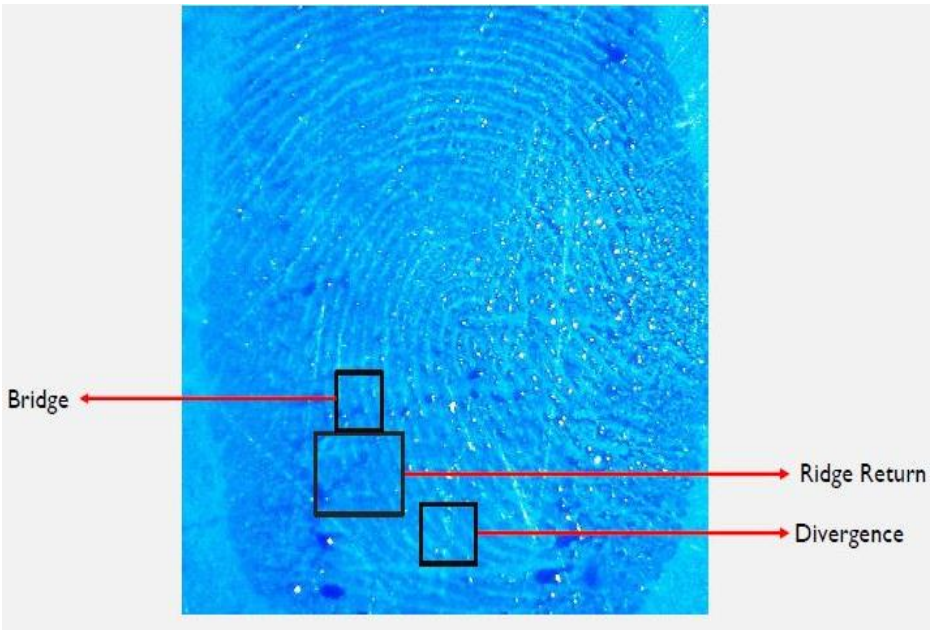

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Figure 9. Visible individual characteristics on plastic surface showing bridge, ridge return, and divergence. 350 351

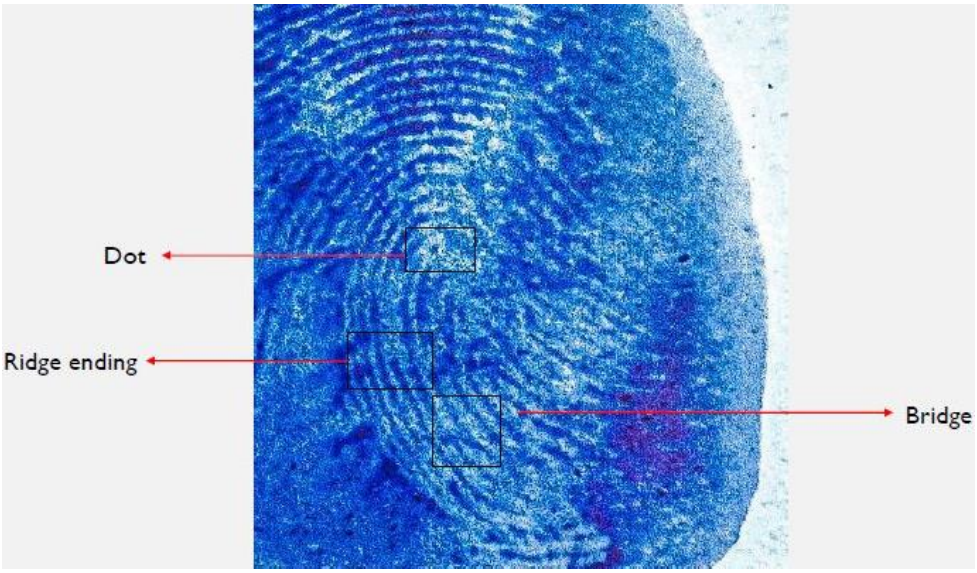

Figure 10. Visible individual characteristics on paper (porous surface) showing dot, bridge, and ridge ending.

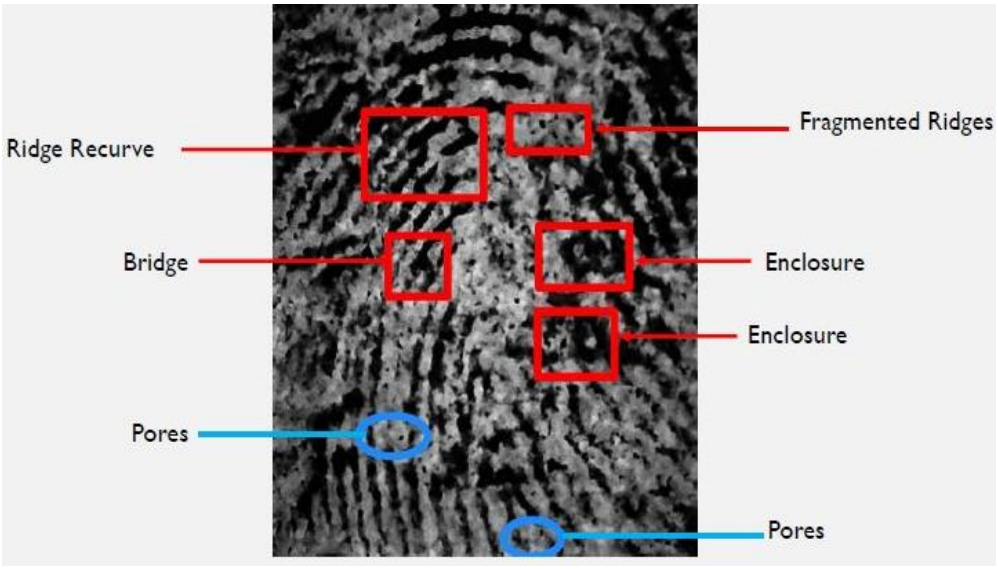

Figure 11. Visible individual characteristics on marble (non-porous surface) showing ridge recurve, fragmented ridges, enclosure, and bridge with level III characteristics.

4. Discussion

The GNSs can be used on porous and non-porous surfaces as they give distinct results on both surfaces. The GNSs developed hidden finger impressions on non-porous surfaces (plastic, marble, glass, and steel) and porous surface (paper) with a clear appearance of class and individual characteristics as well as pores (**Figures 2 and 3**). The outcome may be due to the reaction between carbon and the phosphate present in the sweat, as reported by Yang et al. [12]. Similar studies have been conducted by several scientists to show the importance of carbon nanomaterials including carbon dots (CDS) in the development of latent fingerprint impressions [19–21]. On the majority of non-porous surfaces like glass, metal, tiles, and porous surfaces like paper, the carbon quantum dots were found to provide clear and precise images of latent finger impressions with little background discoloration, exposing outstanding ridge characteristics. Using the synthesized carbon quantum dots nanoparticle liquid formation showed the excellent visibility of the minute details or ridges. A few other compositions of graphene nanomaterials and C dots

were also investigated for such fingerprinting purposes by Chen et al., where researchers combined 1% Carbon dots with starch powder and discovered comparable encouraging outcomes for the fluorescence imaging of latent fingerprints on a variety of non-porous substrates [17].

Similar to the current research, David et al. [21] developed graphene / carbon dots from *Magnolia grandiflora* at various times (14, 16, 18, and 20 min) and further surface-functionalized with hydrogen sulfide (H_2S) to synthesize S-doped carbon quantum dots (CQDs). The synthesized S-doped CQDs had a uniform size according to TEM analysis, along with an amorphous structure, water solubility containing hydroxyl and carboxyl groups, excitation light-dependent characteristics, and high photostability. The synthesized S-doped-carbon nanomaterials have been used in latent fingerprint detection, and it is shown more clearly under UV lamp and has a bright blue fluorescence. This study used S-doped carbon/ graphene nano materials derived from natural resources as high-performance fluorescent probes for the detection of latent fingerprints on non-porous surface material [17, 18].

In several studies, the graphene or carbon nanomaterials a particular class of semiconductor material that is generated by group II–VI binary compounds and has a nanoscale (2–20 nm) size in three dimensions have been utilized for fingerprint development. CdS, CdSe, and CdTe quantum dots (QDs) have been shaped for creating hidden fingerprints with high sensitivity and outstanding background contrast. The nature of cadmium is highly toxic which raises the major concern about using cadmium (Cd)-containing quantum dots [22]. Considering the toxic effects of fluorescent cadmium dots the biomass-generated graphene nano-sheets will facilitate environmentally friendly properties.

5. Conclusions

Fingerprint is a unique identity of an individual since it is an unchangeable feature that differs from person to person. Conventional techniques somewhere fail to detect old fingerprints and are less stable. Therefore, here we developed biocompatible biomass-generated GNSs that produce blue color under a UV lamp. The application of the powdered GNSs was carried out with experiments on various non-porous materials (glass, plastic, silicon, steel, soft plastic, etc.) by keeping in mind that the developed fingerprints on various surfaces will also be helpful in food packaging and sensing sectors where crime prints could be detected on food packaging surfaces.

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coatings

MDPI

Article

Sensitive Fingerprint Detection Using Biocompatible Mesoporous Silica Nanoparticle Coating on Non-Porous Surfaces

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Abstract: In recent years, the development and application of biocompatible nanomaterials in the detection of fingerprints have become a major focus for the forensic sector and crime investigators. This study aims to synthesize biocompatible silica nanoparticles (Si NPs) through cost-effective green methods and will be used to detect a latent fingerprint on a non-porous surface. As a type of environmentally friendly nanomaterial, Si NPs were prepared via an oil–water mixed micro-emulsion templating (MET) approach. Their characteristics and optical properties were measured using EDX-SEM, HR-TEM, FTIR, XRD, and UV–visible absorption. The biocompatibility of the synthesized Si NPs in terms of cell viability was observed, even at high concentrations (83.46% and 75.28% at 20 and 50 mg mL^{-1}, respectively). The developed Si NPs were tested on different surfaces, including plastic, glass, silicon, steel, and soft plastic for the detection of crime scene fingerprints. In this research, it was found that the Si NPs were of the size of 100–150 nm. Results confirmed that synthesized mesoporous Si NPs can be used to detect latent fingerprints on multiple non-porous surfaces and were easy to detect under a UV lamp at 395 nm. These findings reinforce the suggestion that the developed Si NP coating has a high potential to increase sensitive and stable crime traces for forensic latent fingerprint detection, even in packaged food with different packaging surfaces.

Keywords: finger impressions; biosensor; mesoporous silica nanoparticles; latent fingerprints

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1. Introduction

Identification has always been a problem associated with the criminal justice system (CJS); fingerprint identification is itself an already proven magical boon to the CJS. The science of fingerprints is one of the most specialized sciences, which plays an utmost authoritative role in various investigative processes that come across the forensic world. Fingerprints are the impressions made through ridge patterns, mainly on the tips of fingers [1]. Along with the advancements, the term "fingerprints" is not merely limited to finger impressions but also encompasses the impressions obtained by the palm and sole impressions of the human body. Fingerprints are also associated with various other sciences such as forensic chemistry, anthropology, anthropometry, and biometric sciences. It has been known since scientific times that forensic scientists generally approach genetic profiles through blood, semen, hair, bone, urine, etc. [2].

Latent fingerprints are special kind of fingerprints which are not visible to the naked eye and need to be procured and analyzed with more sophistication. There were various traditional methods, such as powder dusting, iodine fuming, cyanoacrylate fuming, etc., which are used as preferred techniques at the scene of the crime for the development of latent fingerprints. These methods have some drawbacks in terms of toxicity, less sensitivity, less contrast, high autofluorescence intrusion, interference of background, and unclear ridges, and not all levels of fingerprints have been developed [3,4]. New approaches have been introduced to improve the quality of hidden finger impressions, making them more affordable, and providing higher efficacy to help in the investigation by identifying the perpetrator in order to overcome these shortcomings. Nowadays, nanoscience is also playing a vital role in the personal identification and characterization of suspects, and offenders being related to each other or to the scene of crime [5,6].

Due to the precise and sensitive analysis in a criminal investigation, nanoparticles are gaining more and more consideration in the field of latent fingerprinting. Some of the specific characteristics of nanoparticles that recommend their exploitation in latent fingerprints are their reduced size and good chemical characteristics. Nanomaterials that are currently playing a major role in latent fingerprinting include carbon dots, quantum dots, rare earth, etc. [7]. High sensitivity, minimal toxicity, and high contrast images are only a few benefits of nanoparticles, some of which are also cost-effective [7,8]. By chemically reacting with the amino acids, fatty acids, and other water-soluble compounds found in the imprint, nanoparticles can physically bond to them. Nanomaterials also have photoluminescence characteristics. These attributes allow for the creation of clear imprints of finger impressions. Nanoparticles made of gold, silver, titanium dioxide, zinc oxide, silica etc. are used to detect fingerprints [9–11].

Fluorescent nanoparticles (NPs) have been claimed to be superior in this class due to their properties of enhancing contrast in latent fingerprints due to their nano-level size and specific optical characteristics, strong fluorescence intensity, and photostability [12]. The fluorescent NPs emphasize the finer features of the buried finger impressions and improve all three levels of fingerprints. Fluorescent NPs can achieve the best contrast quality, enhancement, sensitivity, and selectivity, as compared to other NPs, as well as possess reduced toxicity, less autofluorescence interference, and lower background inference [13]. Because people typically touch their faces and hair, oily substances can be found in dormant finger impressions. Therefore, a fluorescent reagent might be considered a flexible probe for latent finger impression fluorescence imaging if it diffused into the oily substances without rubbing out the hidden impressions with the substrate.

Due to their optical transparency, tiny particle size, large surface area, high fluorescence, robust photo-stability, outstanding biocompatibility, advantageous low toxicity, and high surface absorbency, mesoporous silica nanoparticles (MSNPs) are discovered to be potential fluorescent NPs for utilization in latent fingerprinting. To improve adsorption, silica materials frequently increase surface functionalization with hydrophobic and/or hydrophilic groups. Following that, they offer fingerprint visualization using fluorescence markers. MSNPs have significant use prospects in fluorescence sensors, biolabeling, and medical imaging because of their unique characteristics. The surface controllability of MSNPs is another appealing quality of them as compared to other semiconductor materials. The emission of fluorescence is significantly impacted by changes in surface conditions [14].

By adding silane-modified organic dye molecules, the Stober technique integrates fluorescent NPs. The allylation and hydrolyzation processes can be used to synthesize these changed compounds. Similar optical characteristics with exceptional photostability have been observed in the produced fluorescent NPs and PR254A (allylated pigment red 254). In order to increase the binding affinity of poly (N-vinyl-2-pyrrolidone) (PVP)-coated Si NPs for fingerprint detection, PVP is added to their surface. Fluorescent Si NPs

have the potential to improve fingerprint detection on hydrophobic and hydrophilic surfaces for individual identification due to their simple fabrication and controllable surface qualities [15].

A unique emerging agent for fingerprint detection can be made from mesoporous MSNPs with a particle size as small as 50 nm. A form of dye, methylene blue molecules, can improve the contrast of produced fingerprints when combined with nanomaterials. The two techniques for generating fingerprints are suspension and powder. Additionally, the powder approach exhibits a better effect on fingerprint growth than the other method and is successful in detecting the sweat pores of fingerprints [16]. The inventions and advances made possible by nanotechnology have had a huge influence on how fingerprint development procedures are now more sensitive and selective. Nanomaterials can be used to improve the development of fingerprint ridges, luminous fingerprints, and chemical probing. As a result, it is shown that the spherical mono-dispersed method is extremely effective in leaving fingerprints on both semi-porous and non-porous surfaces [17,18].

Although attempts have been made to increase the detection limit of latent fingerprints (LFPs) by using fluorescent nanomaterials, such as quantum dots, carbon dots, and up-conversion nanoparticles, issues still persist due to their poor detection performance, difficult manufacturing process, photobleaching, and toxicity [15,19,20]. There is a need to develop more efficient and cost-effective Si NPs using easy methods. Therefore, in this study, to overcome the aforementioned limitations, this approach has been synthesized for the development of latent finger impressions.

2. Materials and Methods

2.1. Chemicals and Reagents

Cetyltrimethylammonium bromide (CTAB), ammonium hydroxide, and tetraethyl orthosilicate (TEOS), silica, fumed (SiO_2) (MW 60.08, 0.2–0.3μm), and Whatman® Grade 1 filter paper were purchased from Sigma-Aldrich (St. Louis, MO, USA). Hydrochloric acid (HCl), methanol, ethyl acetate, mercuric chloride, and ethanol were of analytical grade (AR) and purchased from Merck (Mumbai, India).

2.2. Sample Collection

Three individuals provided the samples for this work (three female and one male). To eliminate any type of filth, each volunteer cleansed their hands with soap and water. In order to remove any extra sweat or oil, the fingers were rubbed on the nose and forehead before being placed on various surfaces. On these surfaces, full and partial prints of each participant were obtained. The surfaces taken included both porous and non-porous ones.

2.3. Synthesis of Mesoporous Silica Nanoparticles (MSNPs)

MSNPs were synthesized using some previously reported methods with slight modifications [21–23]. In particular, for the synthesis of MSNPs, 0.055 M n-hexadecyl-trimethylammonium bromide (CTAB) aqueous solution was prepared in 10 mL Milli-Q water under vigorous stirring for 30 min, followed by heating at 60 °C for 15 min. The mixture was cooled to room temperature and further added to a solvent mixture containing 5 mL of methanol, 95 mL of MilliQ water, 3 mL of ammonium hydroxide (NH4OH), and 20 mL of ethyl acetate ($CH_3COOC_2H_5$) under stirring conditions and then 300 μL of tetraethyl orthosilicate (TEOS) was added to the reaction solution. The resulting solution was stirred for 12 h. The synthesized MSNPs were washed with excess ethanol and stored in 40 mL ethanol until further use. The CTAB was extracted by adjusting the pH to 1.6 and stirring for 3 h at 60 °C. After washing three times with ethanol, the pellet was dispersed in 20 mL of ethanol and stored at room temperature for further characterization. The aliquots were sealed tightly.

2.4. Characterization of Synthesized Nanoparticles

The Fourier transform infrared spectroscopy (FTIR) spectra were recorded using a PerkinElmer FTIR spectrometer at room temperature in the 400–4000 cm^{-1} spectral range. The pore size and pore volume were measured following the Barrett–Joyner–Halenda (BJH) method using an Autosorb automated gas desorption analyzer. Brunauer–Emmett–Teller (BET) measurements were done to measure the surface area of the synthesized Si NPs.

The morphological characterization of the synthesized MSNPs was observed via scanning electron microscope (SEM) and transmission electron microscope (TEM). In brief, for SEM, dried samples were coated in a sample holder and coated with gold-palladium sputtering, followed by SEM analysis at different magnifications. Similarly, TEM samples were prepared in ethanol and sonicated for 10 min, followed by dropping on a copper grid and dried under a hygroscopic chamber at room temperature.

The morphology of the synthesized MSNPs was examined using a JEOL 2100F transmission electron microscope (TEM) at 200 kV connected to an energy-dispersive analysis.

2.5. Assessment of Post-Synthesis Stability of MSNPs

The stability of these MSNPs in terms of aggregation and nanoparticle size, prior to soil and foliar application, was assessed using a quantitative non-plasmonic characterization technique (DLS: dynamic light scattering) at different time intervals (0–72 h).

2.6. Cytotoxicity of the Synthesized MSNPs via Cell Viability Analysis

Cell Lines and Culturing

Lung epithelial cells of human origin (beas-2) were purchased from the American Type Cell Culture Collection Center (ATCC) and maintained in RPMI cell culture medium supplemented with fetal calf serum and penicillin−streptomycin (1%), under a CO_2 atmosphere at 37 °C. The growth of cells in the culture medium was confirmed after every second day, followed by refreshing the culture medium.

The biocompatible nature of the synthesized highly porous MSNPs was measured via a 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenylshytetrazolium bromide (MTT) assay. Two days prior to the assay, cells (Hela) were cultured at the density of 5×10^4 cells/well, followed by incubation for 24 h until confluency of 80%, after which the cells were treated with different concentrations of MSNPs (5, 10, and 15 μg mL^{-1}), followed by incubation for 18−24 h at 37 °C. Cells were then treated with 5 mg mL^{-1} MTT reagent to achieve blue crystals that were dissolved in dimethyl sulfoxide; the absorbance was then measured at 540 nm. Results were calculated based on initial and final absorbance measurements taken at 490 and 680 nm, respectively. The cells were also checked for microscopic morphological alterations after the treatments.

2.7. Application of MSNPs for Detection of Fingerprints

The synthesized MSNPs were tested for their ability for detecting fingerprints on different types of surfaces (porous, semi-porous, and non-porous) for crime diagnosis.

Detection Procedure for Fingerprints

A camel hairbrush was used to apply nano-powder to the surface. To develop the prints on the surface, strokes were applied. The substances secreted by the sebaceous, eccrine, and apocrine glands that result in a finger impression were being left on the surface. The fluids were discovered in finger impressions when suggested on the surface after wiping fingertips across the nose and forehead.

By using a hairbrush, the nano-powder of MSNPs was dispersed to the multiple substrates that retained latent finger impressions. The white color of the nano-powder contrasted well with both colored and dark surfaces. The latent fingermarks of nano-powder produced ridge features with little background disturbance.

3. Results

3.1. Synthesis and Characterization of the Synthesized MSNPs

The MSNPs were prepared using ethyl acetate which acted as a pore expansion agent in the presence of CTAB in a silica sol-gel. The overall scheme of the current work is presented in Figure 1. The characterization of the synthesized MSNPs using TEM (Figure 2a,b) and SEM (Figure 2c,d) showed deep, furrow-like mesopores. The functional groups present in the synthesized MSNPs were analyzed with FT-IR spectroscopy in the spectral range of 400–4000 cm^{-1} to identify the presence of silica (Figure 2e). Typical absorption bands of the silicate at 784.71, 1057.45, 1609.33, and 3308.95 cm^{-1} were observed in the MSNPs and were assigned to a siloxane bond, Si-O-Si bending, and silanol (Si-OH) symmetric stretching, [24,25] and bending vibrations [25,26]. The pore size and volume of MSNPs were determined by N_2 sorption (Figure 2h). The MSNPs showed bimodal pores that peaked at 7.2 nm in the pore size distribution. The BET surface area and pore volume of the synthesized MSNPs were found to be 941.88 m^2 g^{-1} and 1.30 cm^3 g^{-1}, respectively gb(Figure 2h).

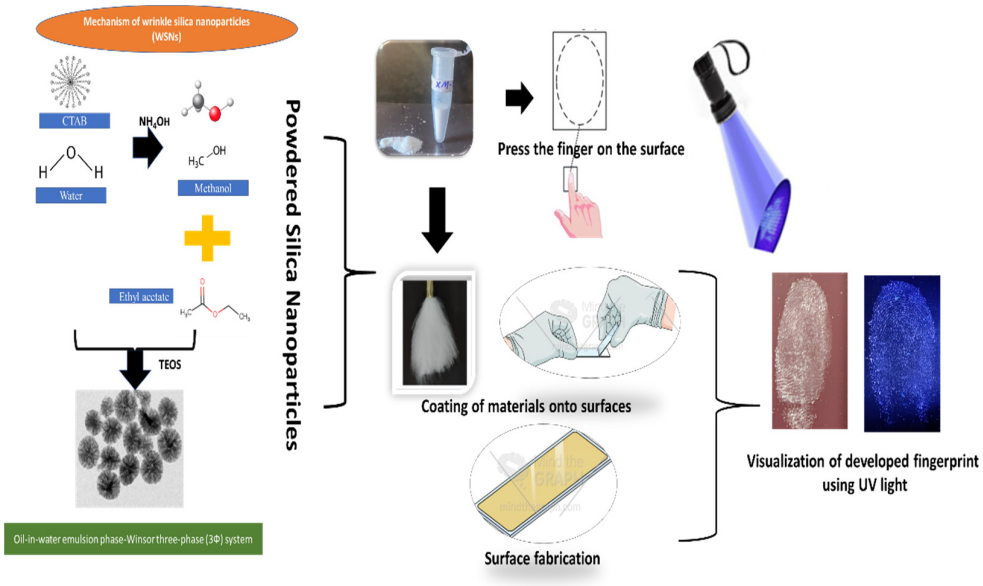

Figure 1. Method development for the application of MSNPs in detecting criminal fingerprints.

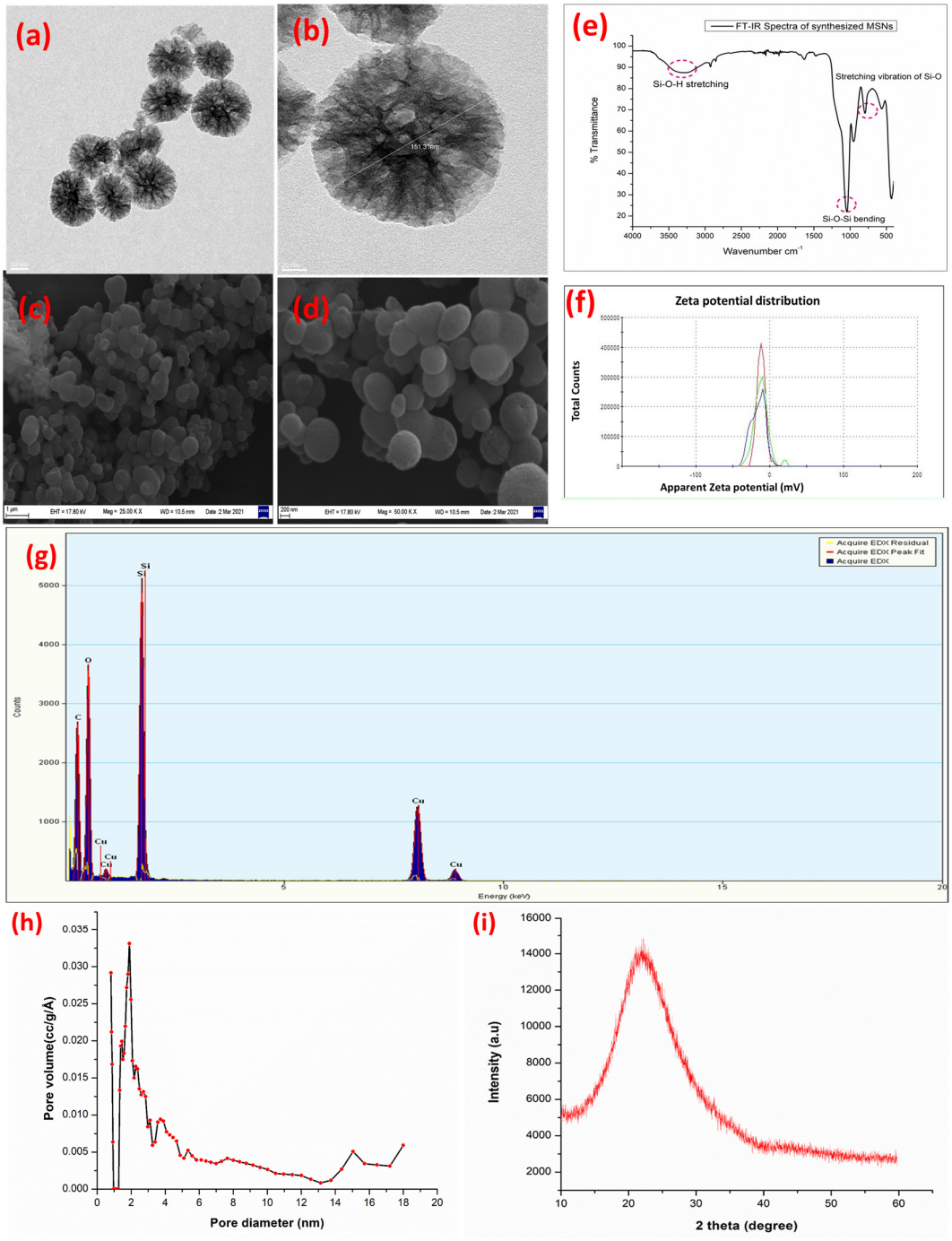

Figure 2. Characterization of synthesized MSNPs. (**a**,**b**): TEM morphological characterization; (**c**,**d**): SEM morphology; (**e**): FTIR measurements; (**f**): Zeta potential; (**g**): EDX confirmation for elemental composition; (**h**): XRD analysis; (**i**): BET measurements.

The XRD pattern of the amorphous silica powder is shown in Figure 2g. The XRD pattern reveals the amorphous nature of the material. The strong broad peak at 22.17°(2θ) (Figure 2i) indicates that the MSNPs that were synthesized chemically were amorphous and no crystalline structure appeared. Hence, the sample is considered as amorphous MSNs. Similar XRD patterns of silica nanoparticles have been reported by other research groups [27,28]. The EDX analysis (Figure 2g) confirmed the presence of major constituting elements, i.e., Si, O, and C in the MSNPs. Moreover, the zeta potential of the Si NPs was

determined to be −27 mV, confirming the colloidal stability of the synthesized MSNPs with a reduced potential for aggregation (Figure 2f).

3.2. Stability Studies of MSNPs via Transformative Changes in Particles during Storage

The stability of the synthesized MSNPs was analyzed using DLS over a time period of 72 h at room temperature (25 ± 2 °C) (Figure 3). The MSNPs displayed stability over 72 h and no changes were detected from the DLS data under different time points, ensuring that MSNPs remained stable until 72 h. It also indicates that these MSNPs can be easily formulated for foliar spray applications. The chemical linking and scheme of wrinkled silica nanoparticles with enlarged pores are presented in Figure 4.

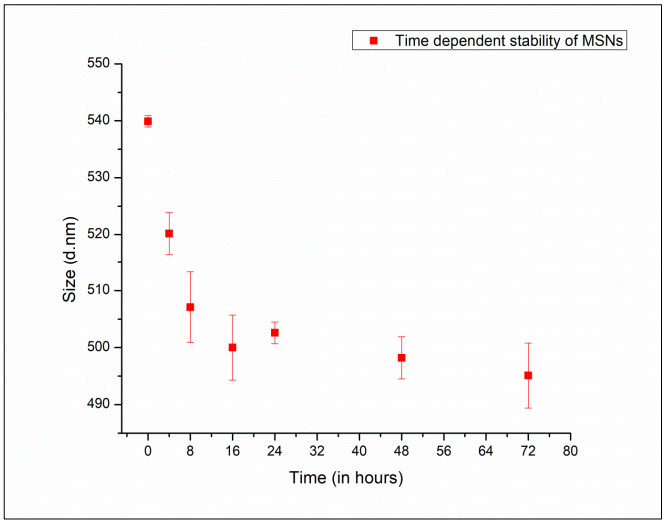

Figure 3. The stability of the synthesized MSNPs analyzed using DLS over a time period of 72 h at room temperature (25 ± 2 °C).

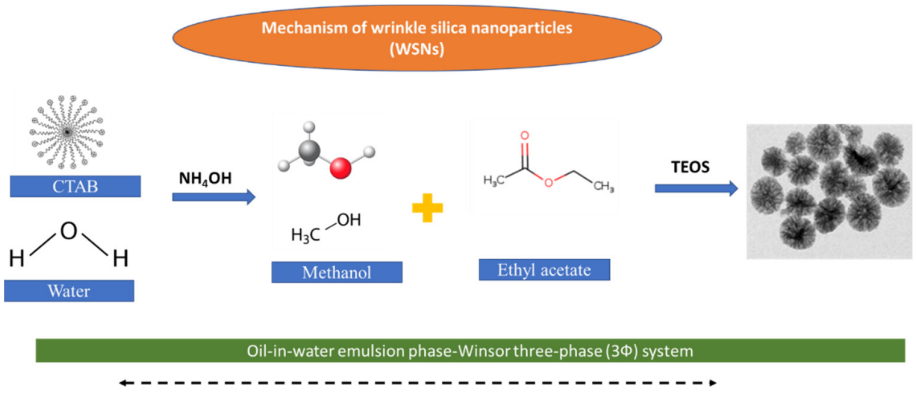

Figure 4. Schematic of wrinkled MSNPs with enlarged pores.

3.3. Development of Quiescent Finger Impressions Using MSNPs

To adhere the powder particles to perspiration and greasy elements, such as grease and oil in the fingerprint residue, powder brushing is a fundamental physical approach. MSNPs were physically adsorbed into the ridges created on the surface during printing at a faster rate due to the presence of sweat and oil in fingerprint residue. The fluorescent MSNPs in the fingerprints were then exposed to 365 nm UV light, which caused them to emit a blue light, thereby revealing the fingerprint imprint.

3.4. Development of Latent Fingerprints by Using the MSNPs

The dormant finger impressions were developed on five different porous and non-porous surfaces, including glass, paper, wooden surface, steel cup, and plastic lid using the MSNPs (Table 1). After developing the dormant finger impressions, they were visualized under a UV torch light (395–400 nm). The fingerprint patterns and ridge characteristics were observed by the naked eye. The plastic, glass, and metal surfaces showed good results based on the size of the nanoparticles and also due to the suspension of the fingermark residue on the surfaces (Figure 5), whereas the prints were not developed on the wooden and paper surfaces (porous surface). The developed finger impressions showed the level 1 (pattern) and level 2 (individual characteristics—bifurcation, trifurcation, dot, etc.) details in them, whereas level 3 (sweat pores) details were not clearly visible.

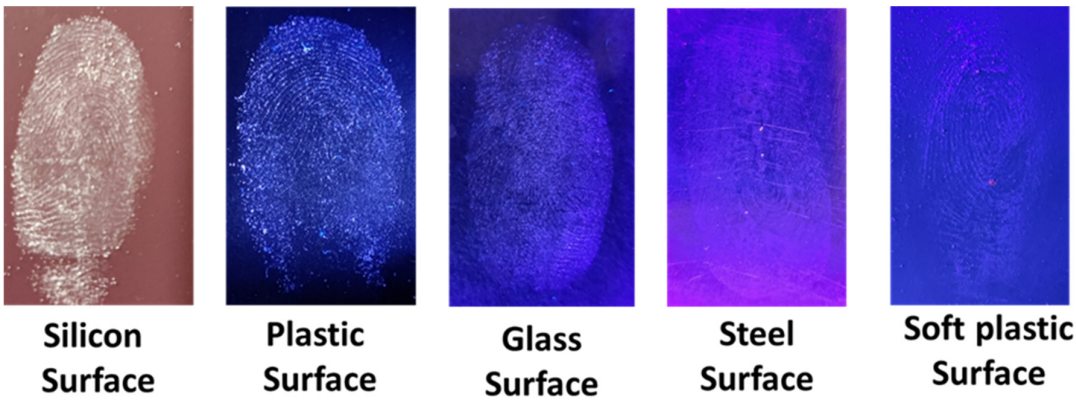

Figure 5. Developed fingerprints on various non-porous surfaces using MSNPs.

Table 1. Latent finger impressions developed using MSNs nanoparticles.

SN	Nanoparticles	Surface	Material	Level-I (Pattern)	Level-II (Ridge Characteristics)
1.	MSNPs	NON-POROUS	Silica phone cover	Visible	Visible
2.	MSNPs	NON-POROUS	Plastic phone case	Visible	Visible
3.	MSNPs	NON-POROUS	Glass slide	Visible	Visible
4.	MSNPs	NON-POROUS	Stainless steel	Visible	Visible
5.	MSNPs	NON-POROUS	Plastic calculator cover	Visible	Visible
6.	MSNPs	NON-POROUS	Transparent poly bag	Not-Visible	Not-Visible
7.	MSNPs	POROUS	Black paper	Not-Visible	Not-Visible
8.	MSNPs	POROUS	Paper bag	Not-Visible	Not-Visible

In addition, the stability of the shelf life of the developed fingerprints on different surfaces, including the silicon phone cover, plastic phone case, glass slide, stainless steel, plastic calculator cover, and transparent poly bag, was evaluated for 15 days and 30 days. It was observed that the silicon phone cover surface and glass surface showed stable fingerprints for <30 days, whereas the plastic calculator showed the stability of the developed fingerprints for <20 days (Table 2).

Table 2. Stability shelf life of developed fingerprints.

SN	Surface Material	Stability/Shelf Life
1	Silica phone cover	<30 days
2	Plastic phone case	<15 days
3	Glass slide	<30 days
4	Stainless steel	<15 days
5	Plastic calculator cover	<20 days
6	Transparent poly bag	<30 days

3.5. Biocompatibility/Toxicity Measurements

The biocompatibility and nontoxicity of the highly porous MSNPs were examined by measuring their effect on the cell viability (MTT and cellular morphology) of normal epithelial cells. Different concentrations of MSNPs ranging from 5 to 15 μg mL^{-1} showed no cytotoxicity on epithelial cells when tested with an MTT assay (Figure 6a,b, respectively). In brief, the percentages of viable cells at higher concentrations of the MSNPs (10 and 15 μg mL^{-1}) were revealed as 89.46% and 96.28%, respectively (Figure 6). Similar morphological changes were observed in Hela cells after exposure to MSNPs at high concentrations (10 and 15 μg mL^{-1}) compared to untreated cells (control).

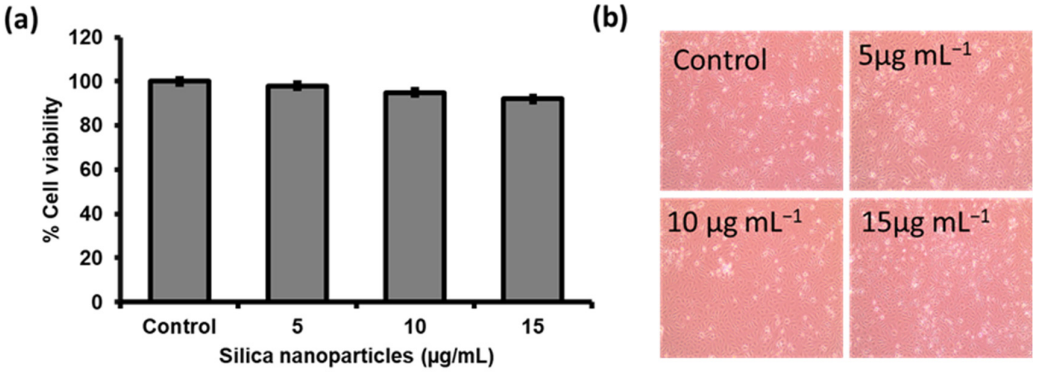

Figure 6. Biocompatibility/cytotoxicity of the synthesized MSNPs.

4. Discussion

The MSNPs can be used on porous and non-porous surfaces as they give distinct results on both surfaces. MSNPs developed latent fingerprints on non-porous surfaces (glass, metal, plastic, and steel) with a clear appearance of class and individual characteristics, as well as pores, whereas fingerprints were not developed on porous surfaces. (Figure 5). This may be due to the transparency of polybags and the lower Rf index difference of polybag with the light in the UV-Visible spectrum. In the case of porous surfaces, surface porosity increases the surface area, thus resulting in the absorption of nanoparticles. The absorption of NPs leads to the distortion of the fingerprints in the form of agglomerates [29,30].

Numerous scientists have carried out similar investigations to demonstrate the value of MSNPs in the formation of latent fingerprint impressions. When compared to porous surfaces, the research by Rajan et al., Zhang et al., and Huang et al. demonstrated that non-porous surfaces produced superior results [17,18,31]. Rajan et al. and Bogeshwaran et al. reported the synthesis of monodispersed and spherical MSNPs from rice husks for possible use in high-definition latent finger-mark development with comparable outcomes [18,28]. On the majority of non-porous surfaces, such as glass, metal, and tiles, and semi-porous surfaces, such as painted wood, the silica nanoparticle powder was found to

provide clear and precise images of latent finger impressions with little background discoloration, exposing outstanding ridge characteristics. Using the synthesized silica nanoparticle powder, excellent visibility of the minute details or ridges was seen [18].

In recent years, researchers have claimed the biocompatible nature of MSNPs when tested on various cells lines and also observed the potential usages of rode-like morphology in cancer theranostics [29]. Hence, MSNPs have shown their advantages in multiple applications, including as adsorption agents and sensors. Similarly, Liu et al., developed silica-based nanostructures of graphene/SiO_2-Ag for increasing the adsorption of biomolecules [30]. In line of sensing or detecting anything on any surface related to food or human direct contact, it is very important to consider the biocompatibility, no toxicity, sensitivity, and cost-effectivity. In order to achieve these major criteria, several researchers have developed a variety of nanomaterials and nanocomposites for developing sensitive sensors. Roostaee et al., developed a nanosensor based on Co-MOF and graphene oxide for detecting the dopamine and uric acids in biological samples with the limit of detection (LOD) of 0.04 μM [32].

On similar grounds, our synthesized MSNPs could be used for the development of sensors against multiple environmental analytes due to their biocompatible nature and cost-effectivity. Most of the micro-sized metal oxide powders blended with the color additives, including dyes, pigments, and luminescent materials, have been used to enhance fingerprint images. Nowadays, nano-sized powders are becoming increasingly more popular in forensic science for fingerprint detection on various surfaces and can also be utilized in food packaging. There are various nanomaterials which have been used for fingerprint detections in porous and non-porous surfaces. Recently, Verma et al., developed the ZnO nano-powder with suitable fluorescent properties and utilized this powder for fingerprint development for surfaces with significant visual detections under UV lights [33]. The most important advantage of all nano-sized materials for fingerprint detection purposes is that almost all nanomaterials are kept in contact with the ridges of the finger to improve the visualization of latent fingerprints. Similarly, gold nanoparticle powders have also been used in mass spectrometry for the identification and imaging of latent fingerprints on non-porous and porous surfaces because of their sensitivity, good selectivity, and inert nature [34]. Richardson [35] reported that industrial titanium dioxide powder could be applied in forensic science for fingerprint detection and showed the best performance on only black adhesive tape surfaces.

On the other hand, MSNP powder has also been tested by several researchers after little surface functionalization. Huang et al., verified that 4-(chloromethyl) phenyltrichlorosilane can be used to modify MSNPs for the detection of aged fingerprints and fingerprints on glass substrates [31]. The developed MSNPs were prepared using different mass ratios of silica and 4-(chloromethyl) phenyltrichlorosilane with 700 nm of Si NPs. These nanoparticles have shown the best LFP detection on only non-porous substrates. Such results have led to further investigations on new types of MSNPs without further surface functionalization for fingerprint detections. Therefore, here we have synthesized green Si NP powder with the ability to detect pre-fingerprints on both porous and non-porous surfaces for versatile surfaces. Although the visuality of these fingerprints is low, they can be utilized in multiple food packaging surfaces due to their easy coating efficiency on various surfaces as pre-fingerprint detection tools.

5. Conclusions

A fingerprint is a unique identifier of an individual since it is an unchangeable feature that differs from person to person. Conventional techniques sometimes fail to detect old fingerprints and are less stable. Therefore, here we developed biocompatible MSNPs that produce blue color under a UV lamp. The application of the powdered silica nano-material was carried out with experiments on various non-porous materials (glass, plastic, silicon, steel, soft plastic, etc.) by keeping in mind that the developed fingerprints on various

surfaces will also be helpful in food packaging sectors where crime prints could be detected on food packaging surfaces. Interestingly, the shelf life of the developed fingerprints was also significantly longer (up to 30 days). Therefore, these MSNPs can be applicative for identifying fingerprints on different surfaces used in food packaging.

Author Contributions: K.B. and D.B.T. performed the experimentation for the application part of the material and contributed to writing the manuscript; R.C. synthesized and characterized the nanomaterials and contributed to the writing of the manuscript; V.K., S.A., and H.P.K.S. contributed to the scientific review of the manuscript and revision of the manuscript; S.S. conceptualized the theme of the manuscript and edited and reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

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REVIW ARTICLE

Role of Fluorescent Substances in Development of Latent Fingerprints: A Review

Kajol Bhati[1], Divya Tripathy[2], Priyanka Chhabra[3]

ABSTRACT

Fingerprints are one of the crucial pieces of evidence in criminal investigations. As fingerprints are majorly found in latent form on the surface, it is necessary to develop those latent fingerprints appropriately without destroying them or leaving out any detail. There are plenty of methods for identifying hidden finger impressions. The powder dusting method, ninhydrin, iodine fuming, cyanoacrylate etc., are traditional methods. Though these procedures help to develop the latent fingerprints, they have some drawbacks such as sensitivity, low contrast, and selectivity as well as high toxicity. To overcome this inadequacy, advanced techniques have been developed using different chemicals and nanoparticles such as metal nanoparticles, fluorescent nanoparticles embedded with quantum dots, rare-earth upconversion nanoparticles etc. The fluorescent nanomaterials enhanced all three levels of fingerprints and provided the minute details of latent fingerprints. This review paper focuses on the role of fluorescence-based methods used for the enhancement of the latent fingerprint and their advantages over traditional methods. As compared to other approaches, fluorescent nanomaterials can obtain optimal contrast quality, enhancement, better sensitivity, and selectivity while exhibiting lower toxicity, less autofluorescence interference, and low background inference.

Keywords | Lie Detector, Forensic Evidence, Polygraph, Narco Test

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INTRODUCTION

Fingerprint impression is the most crucial evidence in criminal investigation. Fingerprints can be left at the crime scene when a person touches an object or surface. It helps in identifying an individual whether the suspect was present at the crime scene .[1] Sweat from the pores on the friction ridge skin of the hands leave finger impressions on objects and surfaces. Pores abound in the ridges of the fingers. Sweat from these pores is deposited in the form of outlines when the fingers touch any surface or object. It acts as a replica of the ridge patterns of the fingers.[2] Sweat is colorless; so when it is deposited on a surface it leaves behind colorless impressions known as latent fingerprints. Secretions from the eccrine (sweat), sebaceous, and apocrine glands on the hand, head, and nose make up latent fingerprint residues. Sweat consists of 0.5 percent minerals, approximately 0.5 % organic compounds, and 98 percent water. Sugars, urea, creatinine, Proteins, uric acid, amino acids, lactic acid, and choline make up eccrine sweat, while wax esters, glycerides, sterol esters, fatty acids, and squalene make up sebaceous sweat.[3]

Latent fingerprint impressions which are present at the crime scene, need to be developed using an appropriate technique. The powder method has been used most widely to develop fingerprint impressions at the crime scene. The powder method includes metallic and

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magnetic powders as well. These methods also possess certain disadvantages like high toxicity, background interference, contrast, selectivity, and less sensitivity with fewer development of all the ridges of finger impressio.[4] Apart from the traditional powder methods, there are chemical techniques that have been used like ninhydrin, iodine fuming but just like powder methods these techniques also have drawbacks.[5]

To overcome this inadequacy, researchers have been exploring many new techniques to enhance the quality of hidden finger impressions and make it cost effective, and providing better efficacy to assist in the investigation by identifying the suspect. The advanced techniques have been developed using different chemicals and nanoparticles such as metal nanoparticles, fluorescent nanoparticles embedded with quantum dots, rare earth upconversion, etc.[6]

Fluorescent Nanomaterials

The fluorescent nanomaterials enhanced all three levels of fingerprints and heightened the minute details of hidden finger impressions. As compared with other approaches, fluorescent nanomaterials can obtain optimal contrast quality, enhancement, better sensitivity, and selectivity while exhibiting lower toxicity, less autofluorescence interference, and low background inference. Oily substances are found in dormant finger impressions due to the normal human habits of touching the hair and face. As a result, if a fluorescent reagent would diffuse into the oily substances without rubbing out the hidden finger impressions with the substrates, it could be counted as an adaptable probe for latent finger impressions fluorescence imaging.[7] Strong fluorescence can be generated by fluorescent materials that have engrossed precise electromagnetic radiation such as ultraviolet, near-infrared, or visible light.[8] When working with multi-coloured or reflective surfaces, where contrast can be an issue with conventional fingerprint powders, the use of fluorescent methods to produce hidden finger impressions has an inexpensive benefit.[9]

Characteristics of Fluorescent Nanomaterials

Due to their peculiar ocular characteristics, the use of fluorescent nanomaterials like up conversion nanomaterials and quantum dots for the enhancement of latent finger impressions has gotten a lot of attention.[10] When fluorescent nanomaterials are utilized for hidden finger-marks growth, they have many benefits, including lox toxicity, high developing contrast and selectivity, and high sensitivity.[11,12]

Toxicity

Some components in quantum dots, like Cadmium, have the potential to be toxic. Furthermore, certain quantum dots have the potential to originate irritation and aversion.[13] Modification in the surface by adding a layer of silica dioxide was documented to reduce the toxicity of quantum dots to a large extent.[14] The upconversion nanomaterials modified at surface level contain low toxicity.[15] The near infrared light-based excitation of upconversion nanomaterials is less harmful to the DNA present in the remaining finger marks, hence, DNA analysis can be performed for the identification of an individual. The use of upconversion and quantum dots are suitable options as they opt for less toxicity or sometimes no toxicity.[9]

Contrast

The up-conversion nanomaterials and quantum dots can release visible fluorescence with high intensity under near-infrared and ultra-visible light. Strong fluorescent emissions can boost the emerging signal while reducing the distraction of the background color, resulting in high enhancing contrast.[11,16] Furthermore, since near-infrared lights emit low energy radiation, they do not cause background fluorescence to be emitted from substrates, eliminating the possibility of background color distraction and, as a result, allowing for high evolving contrast.[9] Because of their strong fluorescent properties, they can achieve a high emergent contrast by increasing the evolved signal and decreased background colour distraction when used for latent fingerprint growth.

Selectivity

Surface alteration is a versatile and efficient method for achieving high selectivity of finger impression. Surface modification can change the electric charge of the fluorescent nanomaterials, allowing them to bind to precise remains in finger impressions through electrostatic adsorption for high emerging selectivity.[17] Furthermore, these fluorescent nanomaterial surfaces can be

modified using the number of functional groups such as amino, carboxyl, and aldehyde. Chemical reactions allow them to selectively mark a particular component in finger marks, resulting in high selectivity.[18] By further addition of molecules like lysozyme, the binding aptamer can help in the conjugation with residues of finger impressions containing lysozymes leads to high selectivity.[19]

Sensitivity

Upconversion and quantum dots are usually small in size. In the case of upconversion fluorescent nanomaterial, the diameter is not more than 100 nm, and in the case of quantum dots, the diameter is not more than 10 nm. The ridge information, such as the fingerprint patterns, or individual characteristics like- termination points, bifurcation, dots, ridge ending, and the location of sweat pores, will not be heavily shielded when using these small-sized fluorescent nanomaterials for the enhancement of the hidden finger marks and gives high sensitivity.[11] Furthermore, these nanomaterials have a spherical shape that can be adjusted through the synthesis process. Surface modification may also be used to adjust the tackiness of the material. As a result, the adsorption on the finger mark remains can be modified, and the emerging sensitivity can be improved even more.[20,21]

METHOD & MATERIALS

Diatomaceous earth is made up of diatoms' remains and is found in the form of powdery silica. Diatoms vary in size from approximately 5 microns to 1000 microns. There are more than 200 genera of living diatoms which are estimated, and almost 100,000 species exist.[22] Diatomaceous earth's fine-grained, highly porous, and lightweight nature makes it suitable for use as an absorbent, insulation medium, mild abrasive, and agent in DNA purification and extraction.[23] Electrostatic force and hydrogen bonds can firmly attach the fluorophores of some cationic dyes present in this material.[25] Diatomaceous earth would be an excellent modulator for the generation of solid and photostable fluorescence because of the shielding effect of silica walls. Therefore, the selection of appropriate fluorescent dyes containing cationic fluorophores is critical. As a standard xanthene dye, rhodamine B is commonly used in solid-state lasers, optical filters, and other applications.[26] Even when encapsulated in a matrix material, it is well recognized for excellent spectroscopic features such as good fluorescence quantum yield and high photostability.[27] Rhodamine B's longer excitation wavelength allows it to be used as an excitation light source in the green region rather than the UV or violet-blue region, which is safer for humans and allows for better conservation of trace evidence such as DNA in fingerprint deposits. For the preparation of novel fluorescent fingerprint powders, diatomaceous earth and Rhodamine B may be excellent silica hosts and fluorescent hosts.

A series of Rhodamine B-diatomaceous earth composites have been successfully prepared as novel fluorescent fingerprint powders using a green, simple, and versatile preparation method based on physical adsorption between cationic fluorophores and porous silica. The fluorescence characteristics of the composite powders change with the amount of Rhodamine B present, due to the different accumulation phases of functional groups in the composite powders. The current research was the first to demonstrate a new mechanism for developing and improving latent fingerprints by using fluorescence properties of as-prepared fingerprint powders by qualitative and quantitative analyses. According to the mechanism, a photo recording and enhancement system with optical devices (532 nm alternate light source, cell phone camera, and 580 nm long-pass filter) and image analysis techniques (channel separation with PhotoShop and grey analysis with Image) were developed.[28]

Earth Upconversion Fluorescent Nanomaterials

Rare earth upconversion fluorescent nanomaterials (UCNMs) are materials that have been doped with rare earth elements. They emit a shorter wavelength light when excited by a longer wavelength light. When excited by NIR light, they produce visible light. UCNMs have a number of distinct attributes, including small emission spectra, low toxicity, and high intensity. They can also be chemically functionalized. Background fluorescent interferences are excluded since they can be excited using NIR light, resulting in increased evolving contrast. As a result,

UCNMs show improvement for developing latent fingerprints with high contrast, selectivity, and sensitivity. NaYF4 co-doped with Yb3–Er3 ions (NaYF4:Yb,Er) is the most widely used UC material today which is also capable of emitting the brightest UC fluorescence.[21]

Wang et al., also prepared the upconversion nanomaterials using NaYb0.98F4:Tm with the help of solvothermal technique. Generally, NaYF4:Yb, Er UCNM production was focused on a single near-infrared to visible method that allows finger impressions to be observed by sensing visible light under near infrared light excitation. Otherwise, it can be prepared by dual method that is near-infrared to near infrared and near-infrared to visible technique. The synthesized upconversion nanomaterials had a versatile fluorescent marker quality and used a dual-mode production on porous, non-porous semiporous surfaces. This method produced the enhanced fingerprints with better contrast, high selectivity, and sensitivity under both near-infrared to near infrared and near-infrared to visible methods.[29]

Bilayer systems based on conjugated polymers

Bersellini et al., suggested a new notion based on the electropolymerization of polypyrrole on surfaces such as gold, platinum, silver, and aluminum alloy (Ergal).[30] Hillman et al., used this technique to improve latent fingerprints on metallic surfaces like brass or stainless steel by electrodepositing conjugated polymers including Polypyrrole, Poly (3,4-ethylenedioxythiophene), and Polyaniline. The process in which the electrochromic material allows for the manipulation of optical properties (polymer color) by applying an electrical potential, has the efficacy to enhance the latent fingerprints. In spite of that, the visualisation of the fingerprint image under UV light is sometimes needed, particularly in case of dark or multicoloured backgrounds. Therefore, second layer of fluorescent conjugated polymer can be added to enhance the contrast.[31,32]

Conjugated polymer shows advantages over molecular fluorophores, including high emission, low-cost synthesis, and low toxicity. A series of fluorescent materials based on conjugated polymers for a variety of applications has been synthesised by C.V. Costa et al., The precursor monomers of those conjugated polymers were insoluble in water.[33]

The usage of an aqueous medium for electrodeposition of the polymer was one of the foundation approaches proposed by Hillman et al. This approach was based upon the assumption that the presence of fatty acids in the remains of the latent fingerprints serve as an insulating cover on which the polymer must not be deposited, resulting in a detailed finger impression imaging.[34]

C.V. Costa, et al., strategized a technique for the latent fingerprint development based upon the conjugated polymers bilayer, containing first layer of polypyrrole as electrodeposition on a stainless steel having a latent fingerprint. The second layer made up of fluorescent poly (2'2'-2"5'-terthiophene which was electrodeposited on the first layer. This technique showed the detailed structure of latent fingerprints containing ridge pattern, class and individual characteristics. The fluorescent bilayer system interacts with the unexposed area of the substrate which helped in the enhancement of the contrast between surface and fingerprint, has low toxicity as materials used for the synthesis are less toxic in nature, and easy development of the polymer film using Galvanostatically and Potentiostatically methods. This technique combines UV and visible light for better enhancement of fingerprints and can be used as suitable one on stainless steel surface.[33]

Quantom Dots

Cai et al., used an extremely fluorescent water-solvable cadmium-telluride quantum dots capped by mercaptosuccinic acid basic solution in 1–3 seconds to enhance hidden fingerprints on numerous nonporous exteriors. Mercaptosuccinic acid cadmium-telluride quantum dots showed the higher sensitivity and image excellence when developing dormant fingerprints.[35]

Chen et al., worked on dual visual senser based on polymer dots that helped in imaging of fingerprints. They embedded ninhydrin into the Polymer dot matrix after scheming and synthesising two forms of near-infrared fluorescent polymers. The characterization of nanoparticles has been done by transmission electron microscope and dynamic light scattering. The fluorescence remained measured using fluorometer under 450 nm excitation and absorption spectra under UV-Visible spectrophotometer. The colorimetric

and fluorescent dual-readout capabilities of the Polymer dot assay to spot dormant finger impressions on absorbent and non-absorbent exteriors were demonstrated. The chemical groups were also imbedded onto the surface of the nanoparticle to examine the process responsible in the growth of fingerprint. The assay has been used to image hidden fingerprints on checks and note paper. This technique helped in detecting hidden fingerprints on all smooth surfaces with low background interference, high resolution, and contrast. It showed all the particulars of fingerprints from level one to three.[36]

Conjugated polyelectrolyte dots have become a choice in bioimaging probes as they contain low cytotoxicity, strongly biocompatible, and have outstanding fluorescence brightness. Conjugated polyelectrolyte dots are made by dissolving water soluble conjugated polyelectrolytes in water to produce an aqueous colloidal solution. They are commonly found as particles like nano sized in water, despite their polar side chains increasing their water solubility. This is because the polymer chains appear to accumulate in aqueous environments due to the inherent hydrophobicity and structural rigidity of the main chains. The Conjugated polyelectrolyte dots amphiphilic features can be precisely balanced with the help of surfactants with sufficient hydrophile–lipophile-balance values and then the fluorescent nanoparticles can be efficiently transferred to the oily phase of a latent fingerprint while the latent fingerprint remains intact. Kim et al. worked on different variety of Conjugated polyelectrolyte dots to develop the hidden fingerprints using fluorescent imaging probes. The hidden finger impressions could not be stained by the aqueous Conjugated polyelectrolyte dots colloidal solutions alone. The Conjugated polyelectrolyte dots nanoparticles were transferred directly to the hidden finger impressions when an acceptable surfactant was applied to the aqueous mixture and then sprayed onto the hidden finger impressions. These showed the extremely distinct fluorescent images of latent finger impressions. Cationic surfactant also helped in enhanced the dormant finger impressions and made them brighter. This technique is convenient, simple, and universal which helps in the higher visualization of hidden finger impressions.[7]

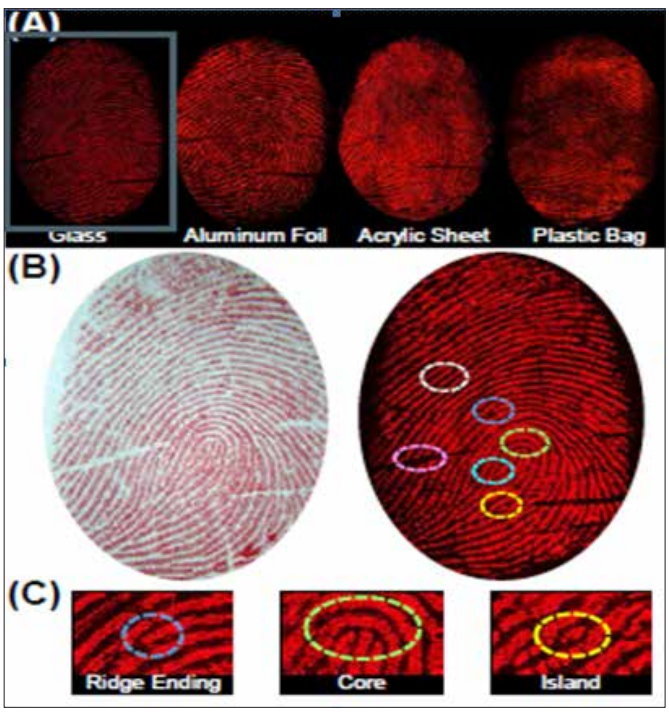

Figure 1: A) Hidden finger impression pictures enhanced using polymer dots on crystal, aluminium paper, acrylic piece, and plastic container. (B) finger impression assessment marked using a Polymer dots (right) and red inkpad (left). (C) Level one-three data, including centre, ridge ending, bifurcation, island, scar, and pore, are visible in high-resolution fluorescence images of latent fingerprints. A 450-nm LED light with an orangish filter was used to excite all fluorescence images. Copyright © 2016, American Chemical Society

Non-metals Nanoparticles with Fluorescence Characteristics

Rajan et al., synthesized the silica nanoparticles using rice husk by thermochemical treatment which were then dyed with natural dyes. Fourier-transform infrared spectroscopy, Field emission scanning electron microscopy, X-ray diffraction analysis, and forensic alternate light source were used to record and characterise the powders' photoluminescence. By producing dormant fingerprints left on various multicoloured substrates, the efficacy of three fluorescent variants of silica nanoparticles powders and industrial fluorescent powder was studied. Rice husk was successfully used to make spherical fluorescent silica nanoparticles. Amorphous spherical silica nanoparticles with an average crystallite size of approximately 200 nm were discovered during characterization studies of coloured silica nanoparticles. Once heat was

applied and aged at room temperature, silica nanoparticles doped with curcumin pigment showed the best stability and greatest fluorescence. Electron microscopy and surface tests results on different surfaces showed that the dye doping method did not compromise the efficiency of the coloured silica nanoparticle. The results showed that it had strong photoluminescence, allowing for adequate contrast for fingerprint examination on problematic and challenging exteriors. The spherical mono-dispersed nanoparticles also improved the powder's transparency and selectivity.[37]

Nanofibres

Junior et al., prepared dansyl-based fluorescent nanofibers using Polycaprolactone and dansyl cadaverine or dansyl glycine derivative by electrospinning method. The characterization was done by thermal analysis, scanning electron microscope, FTIR, and fluorescence spectroscopy. With 2% fluorophore concentration in dansyl cadaverine or dansyl glycine, a working distance of 12 cm among the syringe tip and collector, and a voltage of 17 kV, the best experimental conditions for homogeneous, even, and bead-free fibre forming of all samples were discovered. Electrospun Polycaprolactone/ dansyl cadaverine and Polycaprolactone / dansyl glycine nanofibers emit large emission bands at 485 and 415 nm, respectively, and are fluorescent. This research provided a simple, low-cost method for producing electrospun fluorescent nanofiber materials for forensic applications such as the production of hidden fingerprints on metallic objects such as cartridge cases, knives etc. As compared to the majority of well-known traditional methods, like Powder dusting and cyanoacrylate fuming, the proposed technique has many benefits over traditional techniques including solvent and raw materials with low-toxicity, easy regulation of polymer film formation, and attainment of evidence containing hidden fingerprints on metallic objects of various sizes and shapes, liable on electrospinning collector settings. As a result, this novel approach enabled the high-definition visualisation of formed hidden fingerprint images, as well as the identification of class characteristics, ridge patterns, and singular points of fingerprints.[38]

Benzazole dyes have characteristics like high sensitivity, stable and intense photoluminescence which can enhance the latent fingerprints. Stefani et al. considered benzazole dye to prepare micro-structured fluorescent powder to develop the dormant fingerprints present on various surfaces having different color in background like multi-colored, white, and dark. The fluorescent powders were extremely selective and sensitive which only sticked to fingerprints rather than the whole treated area. Irrespective of the color of the surface, the high fluorescence produced by the powder provided a high disparity with the finger impressions, making them easy to recognize and capture. Silica was used as the matrix in the formulation of powder having a 1:100 and 1:300 mass ratio, having ethanol or aqueous solution underneath encompassing settings. Silica is non-toxic, biodegradable, and environmentally safe in nature. The excited-state intramolecular proton transfer mechanism and the high Stokes change detected for the integrated dyes were responsible for the proposed powders' high chemical and photophysical stability, resulting in a extended shelf lifespan. This too permits for the long-term storage of processed evidence without any deterioration of the exposed fingerprints. ultraviolet-visible absorption and fluorescence emission spectroscopy were used to determine the photophysical properties. Assessments were made with commercially obtainable fluorescent, white, and black powders for various types of surfaces to determine the efficacy of these industrialised residues. When exposed to long wavelengths of ultraviolet light at 365 nm, the created micro-structured powders showed intense visible light emission within the blue-green field, and a pointy distinction with the finger impression deposits was discovered, developed discrete ridge data on all studied exteriors. The method is cost- effective and also a simple technique to develop the hidden fingerprints on various kinds of surfaces with distinct levels of information. This fluorescent powder is versatile in nature and can be used in the forensic examination as a multipurpose choice.[39]

Numerous fluxes, such as NaCl, NH4F, and NaBr, were used by Dhanalaskhmi and her colleagues for their study to synthesise novel BaTiO3:Eu3+ (5 mol percent) nanophosphors through a solution combustion path. The effect of

the fluxes on the prepared nanophosphors' physical, structural, and photoluminescence possessions was thoroughly investigated. The cubic structure of the products is verified by powdered X-ray diffraction outcomes. The synthesized samples were sphere-shaped with accumulation, according to the morphological studies. The addition of fluxes results in a significant increase in the red emission intensity in the photoluminescence study. It was discovered that NH4F (3 weight%) was an effective flux for lowering the temperature formation, morphology improvement, and increasing the photoluminescence strength by two-fold. The samples' photometric properties were calculated and found to be very similar to commercial BaTiO3: Eu3+ phosphor. The fingerprints that have been visualised show that they were highly sensitive, have good contrast, and have no background interference. The results showed that the optimised sample opened up a new path for the easy visualisation of hidden finger impressions in anti-counterfeiting, forensic sciences applications.[40]

DISCUSSION AND CONCLUSION

Latent finger print development is cornerstone in any criminal investigation. Fingerprints are the crucial evidence for the identification of a suspect or culprit in any crime scene. It identifies the individual as fingerprints are unique; no two individuals share the same fingerprint. However, there is a profusion of fingerprint enhancement techniques for the visualization of hidden finger impressions. Powder method is one of the oldest techniques which are still used to develop the prints at the crime scene but it has its own drawbacks like less sensitivity, background disturbance, interference with cellular material visualization techniques, and might not enhance all the levels of finger impressions. Recently, the use of fluorescent nanomaterials like up conversion nanomaterials and quantum dots for the enhancement of latent finger impressions have attracted a lot of attention. Fluorescent nanomaterials for fingerprint development have shown many benefits like low toxicity, high developing contrast and selectivity, and high sensitivity. Rare earth upconversion fluorescent nanomaterials doped with rare earth elements can enhance the dormant finger impressions and emits the brightest upconversion fluorescence. On the other hand, a conjugated polymer based fluorescent material also develop a detailed image of finger impression that can be cost effective and having low toxicity with high emission of fluorescence. Similarly, quantum dots showed a higher sensitivity and image excellence when developing dormant fingerprints from level one to three. Therefore, fluorescence-based nanomaterials method developed here allows for successful imaging of hidden finger impressions on a variety of absorbent, non-absorbent, and semi-absorbent materials with high characterisation of first to third level detail, which is in line with the forensic science standard for finger impression identification. IJFMP

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REVIEW ARTICLE

Role of Nanotechnology in Techniques in Fingerprints Enhancement

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ABSTRACT

Fingerprints have been utilized in criminal and judicial investigations for establishing the identity of the accused/suspects for a long time. Fingerprints are an effective tool for determining who committed a crime. Nonetheless, easily detectable or visible marks are infrequently found at a crime scene; most of the time, they are latent, requiring the use of special methods to identify them. Fingerprint comparison should be cost effective and time bound to quickly obtain results with quality assurance. In this case, nanotechnology and its continued development have resulted in a range of applications in forensic science. Nano particles have been proposed as a solution for fingerprint detection and enhancement due to their versatility and smaller particle size. Because nanoparticles do not alter the composition of evidence, they can easily aid in the detection of high-resolution prints, and these evidences, unlike conventional techniques, can be re-used for any other chemical treatment. In most legal science research facilities, traditional methods such as black powder, fluorescent powder, and white powders are used. This review paper summarizes the various types of nanoparticle techniques that can be used for fingerprint identification and comparison, such as Camphoric-based Nano carbon, Acetylated cashew gum based silver nanoparticles and so on.

KEYWORDS | Nanoparticles, Fingerprint Analysis, Conventional techniques

INTRODUCTION

Fingerprints have been for ages the most important evidence collected from a crime scene. They are extremely useful in connecting the three dots of every crime: victim, author or individual, and object or location.[1] As LPs are constituents of natural secretions secreted from friction ridges and contaminants present on a surface, crime scene investigators regularly deal with the development and extraction of latent fingerprints from a crime scene.

Powder methods, silver nitrate methods, and iodine fuming are the general methods used in the enhancement of latent fingerprints. The method of choice is determined not only by the nature of the fingerprint but also by the substrate or supporting matrix on which the print is present.[22] The powder technique is the most widely used strategy in fingerprint development. Its mechanism is based on the sweat and oil components that have settled in the print's ridges. Powder is deposited in the ridges, and the print appears as a result of pressure and electrostatic forces between the powder and the oily components.[18] These methods, however, have less sensitivity, toxicity and, above all, the low contrast. Thus, nanoparticles are used to resolve this problem.[10]

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Ultrafine or minute particles between 1 to 100 nano meters in dimensions are defined as nanoparticles. These particles constitute nanotechnological components. Due to their smaller size, nanoparticles can be used in different industrial applications. In forensic science, their vital role and impact can be seen and this area is known as nano-forensics and is the most recent progress in forensic science. One of the major roles is seen in the development of fingerprints as they are very helpful in developing impressions of fingerprints regardless of their substrate.[26] Due to their smaller particles, they are incorporated into the ridge spacing of prints, and these particles are also non-reactive which is very useful in developing old-age finger marks. In recent years forensic researchers have developed different methods including nanoparticles, which have advantages such as high sensitivity, low toxicity, and high-contrast images, some of which are also cost-efficient.[5] As nanotechnology improves over time, new instruments have also been developed to keep pace with the progress. In the past years, nanotechnology has made a lot of advancements and these advancements need to be brought to notice so that forensic experts can use it to get results with more efficiency and accuracy. This review paper establishes a summary of different nanotechnology methods to develop and enhance fingerprints.

METHODS

As nanotechnology is still evolving, several techniques have been implemented to detect fingerprints. Each technique has distinct and significant advantages for detecting fingerprints, which are discussed below:

Acetylated cashew gum based silver nanoparticles

Cashew-gum is a gum secreted from the Anacardium occidentale L. tree, which is found in north eastern Brazil. This polymer provides steric hindrance to nanoparticles and occupies the surrounding surface due to charged particles that provide electrostatic repulsion. Cashew-gum separate is additionally blended in with silver nanoparticles to diminish the harmful and destructive nature of silver nanoparticles and further increasing the development power. Cashew gum diminishes the corrosive nature of AgNP (Silver Nanoparticles) as it synthetically comprises of β-D-galactose (72%), α-D-glucose (14%), arabinose (4.6%), rhamnose (3.2%), and glucuronic corrosive (4.7%).

A suspension of silver and cashew-gum was developed for the production of latent fingerprints, for which acylated cashew-gum was distilled and synthesized. It was further separated by different amounts (0.5, 1.0, 5.0 mg/mL) and blended separately for approximately 30 minutes with 1 mM AgNo3 solution. The solutions at low temperature were then mixed drop wise with a freshly prepared borohydride solution (NaBH4), a molar ratio of 1:10 silver. These were passed onto a falcon tube and left for 24 hours on the formulation of these solutions. They were centrifuged for 15 minutes at 3,600 R.P.M. Hence, forming acylated cashew gum silver nanoparticle suspension has been further analysed with Atomic Force Microscopy (AFM) and Transmission Electron Microscopy (TEM).

For the enhancement of latent fingerprints from the surface of the alkaline paper, it is submerged in the suspension of varying focuses (0.5. 1.0, 5.0 mg/mL) trailed by withdrawal and prompt perceptions. The withdrawal and submersion were permitted to be saved for 3 distinctive time spans (1hr, 2hr, 24hr). This technique developed yellow colour prints, therefore increasing the contrast and ridges were more defined and clearer as compared to traditional methods.

Hence, this technique is quick, easy, low-cost, and uses biodegradable chemicals, Due to its fast functioning and non-toxic nature it can also be used at crime scenes making fingerprint production fast and secure.[1,25]

Camphor bases enhancement

Impurified camphor tablets ($C_{10}H_{16}O$) were used in this technique, which were burned into carbon soot and collected in a petri dish. Carbon sooth can be differentiated on the basis amount of carbon and size of the particles.

Camphoric carbon powder was synthesized and used on absorbent and non-absorbent surfaces such as plastic files, book covers, paper, coffee cups, and so on. The prints were said to be provided by rubbing the donor's finger on the forehead in order for the sweat to collect. The powder dusting method was used to produce fingerprints

on different surfaces, and excess powder was extracted with the aid of a fiberglass brush. For the evaluation of developed fingerprints automated fingerprint identification system was used and for the evaluation of carbon soot particles SEM and EDX was used.

The outcomes were uncovered by AFIS (Automated fingerprint identification system) in view of different surfaces, for example, 27 minutiae were formed on metal and plastic surfaces. Further in the identical conditions the carbon soot showed more enhaced images of minutiae by showing 33 on plastic file surfaces and 36 on metal surface.

This method untangled the fact that the camphoric-based powder produced better results than the conventional black powder. This powder is minimal expense and harmless to the ecosystem, and it tends to be utilized at a crime location. This method revealed characteristics of carbon soot such as water solubility, cytotoxicity, and biocompatibility.[2,15]

Red emitting CaTiO3: Pr3+ nanophosphors

In this technique Red emitting CaTiO3: Pr3+ nanoparticles with persistence timing of 20 minutes have been synthesized so as to produce or develop latent fingerprints. CaTiO3: Pr3+ was first synthesized further used in development of latent fingerprints through facile dusting powder method. These long after glow nanophosphors luminescence particles are great source of developing the prints as they have high quantum efficiency. Due to the purkinje effect and scotopic vision the human eyes are less sensitive to red color. Hence, making phosphorus strongly desirable in CaTIO3 compound. This compound reacts with the sweat present in the minutiae and provides high contrast red color latent fingerprints.

For the synthesis of CaTiO3, the sol-method was used, and Ca (NO3)2Pr(NO3)3.6H2O was homogeneously dissolved in iso-propyl alcohol for this experiment. The solution was vigorously stirred for 15 minutes before being combined with Titanium Tetra-iso-propoxide (Ti (OC3H7)4). A 1:10:4 ratio of Titanium isopropoxide: IPA: water was used to make the suspension. As a result of the exothermic reaction, a gel-like structure was formed, which was then placed on a hot plate to form powder. An additional annealing step is performed at temperatures ranging from 6000 to 10000 degrees Celsius.

SEM (Scanning electron microscope) was utilized to examine the surface geography, and surface highlights of CaTiO3 incorporated by sol-strategy. Since ordinary nano phosphor blend techniques produce huge molecule sizes going from 0.2 to 2 nm, sweat pores are filled and fingermark affectability is decreased. Tiny particle sizes formed fingermarks with level-3 characteristics such as sweat pores and minutiae, according to Scanning electron microscope findings.

The test was also performed on fingerprints from a 28-year-old man who was asked to give fingerprints by rubbing his finger on his forehead and pressing it on a required substrate. CaTio3: Pr3+ was finely ground in a motor-pestle after being annealed at various temperatures. The excess powder was blown off after it was dusted over the fingermarks with a soft squirrel brush. The fingermarks were then excited for about 15 minutes in a UV chamber. The findings revealed that when the substrate is auto-reflective, the level-2 and level-3 characteristics of fingermarks are not apparent. Otherwise, the fingermarks were more noticeable and had a higher contrast, exposing the ridges, minutiae, and sweat pores.

The benefit of this approach is that by exciting the prints in a UV-Chamber, the fingermarks can be seen at any time depending on the requirement. Phosphorus can also be preserved for longer periods of time due to its organic origin. Since they provide high contrast images with specified characteristics, these long after glow nanophosphors are the best alternative to conventional powder methods. 8,12,

Greener synthesis of Copper oxide nanoparticles

Copper oxide nanoparticles (CuO) is highly specific metal oxide that possess differement promoting features such as electrochemical activity , high specific area, redox potential and most importantly stability in the solutions. But, due to its corrosive nature it needed to be synthesized by sol method with an organic compound. So, in this experiment Green tea extract is used to coat the Cuo nanoparticles so, thaty It could form non-corrosive nature and eco-friendly.

In the initial phase Copper sulfate (CuSO4.5H2O) was used to form CuO without

purification and a green tea from the market. For the preparation of green tea. 1 gm of it is mixed in distilled water (50 mL) in an Erlenmeyer flask. A yellow color solution was obtained after 20 min of stirring at 700c to 800c. The extracted solution is then stored at 40c in a refrigerator. In an ultrasonic bath 40 ML of CuSO4.5H2O is mixed with 20 ml green tea extract. The greenish-yellow color of the extract gets converted to brownish-black. Integrated CuO arrangement was centrifuged at 10,000 rpm and the supernatant was eliminated. The brownish-black crystals obtained from centrifugation were removed from the flask. Further, these crystals were crushed and converted to powder form.

The latent prints were established on various non-permeable surfaces like glass, white paper, margarine paper, and steel utilizing by powder dusting strategy. Green tea goes about as a balancing out, covering specialist and a decreasing specialist for CuO. Hence, for the characterization FE-SEM (Field Emission Scanning Electron Microscope) was used and it revealed the magnitude of nanopartilces from 500 to 900 nm and spherical in shape. The results were easily visible by naked eyes and the black color given by the crystals was defining the ridges, minutiae, and sweat pores.

This method for devlopement of latent fingerprints through CuOand green teas is eco-freindly, cost effective and majorily non- corrosive making it to use at crime scene. 4,11,17

Tetraethoxysilane (TEOS) and phenyltriethoxysilane (PTEOS) with silica gel

In a rotator tube, 30 ml ethanol, 5 ml deionized water, 2.5 ml each of tetraethoxysilane (TEOS) and phenyltriethoxysilane (PTEOS), and 2.5 ml each of tetraethoxysilane (TEOS) and 2.5 ml phenyltriethoxysilane (PTEOS) were joined. 2 mL ammonium hydroxide arrangement was applied to this, and the arrangement was turned for the time being. The suspension was centrifuged during this period (3 min at 3000 rpm). The main cycle included centrifugation and extraction of the fluid/fluid stage from water to dichloromethane, joined by dissipation of the natural stage to dryness. Subsequently grouping of wash methodology and centrifugation, the item was disengaged in the second workup measure.

The connected colour (25 mg) was broken down in the ethanol before the salinization reagents were added for the different colour doped particles. Prior to applying the salinization reagents, 25 mg of titanium dioxide was added to the rotator tube. A 1:100 weakening of the provided carbon dark arrangement in water was applied to the antecedent answer for carbon dark particles. Particulate magnetite was set up as indicated by distributed techniques for TEOS: PTEOS-covered attractive particles, and 5 ml of the suspension in water was applied to the antecedent arrangement again for 5 ml of TEOS: PTEOS-covered attractive particles.

New prints (roughly 20 minutes before tidying), just as matured prints (different conditions itemized inside), were examined. A 21-year-old lady and a 33-year-old man both Caucasians stored their fingerprints on unused non-permeable glass magnifying lens slides (VWR Int, Leicester, UK), which were utilized precisely as taught. The prints were applied in one of two different ways: the fingerprints were scoured on brow prior to pushing on a superficial level, or the fingers connected with the surfaces after the latex glove was eliminated. A falling pipette was used to apply a small amount of suspension to the print (500 ml of 10% (w/v) in 97:3 (v/v) water/ethanol). The excess suspension was gently washed away after 2–3 minutes with surplus water.

The print was then permitted to dry normally. The slide could likewise be lowered in the suspension for 5–10 minutes. By gravity, the abundance engineer was taken out, and the surface had the option to air dry as in the past. As tidying specialists, various sieving divisions were utilized. The fluorescent sifter sizes of 45–63 mm and toned particles and 63–90 mm for sub-atom embedded particles were the most straightforward to use and gave the best portrayal prints. Instances of prints made on glass slides with the fluorescent colour rhodamine 6. The fluorescent and colour doped particles would be advised to definitions when all is said in done, however the implanted particles actually furnished prints with great definitions. On a tempered steel sink top and a research centre benchtop, great outcomes were acquired, and the idea was practically identical to that seen with fluorescent modern powders and enhanced were visible with aluminium powder.5,23,28

Fluorescent Starch-based Carbon Nanoparticles

Malic corrosive and ammonium oxalate were utilized as crude materials in a one-pot pyrolysis course to make N co-doped carbon nanoparticles. The carbon-Nanoparticles of quantity wt1% were joined with characteristic starch to make a powder that fluorescent in dazzling blue in the dry strong state. These materials were joined with the uncommon benefits of the primary powder part's preeminent flowability and CNPs' remarkable photoluminescence.

The usage of nano-carbogenic powder as a novel UV fluorescent imprint for totally making whole fingerprints was the point of convergence of this research.

Conventional staining materials like iodine fume, industrially 502 cyanoacrylate stick fume, and TiO2 powder was utilized as controls to check the viability of fluorescent starch powder as fluorescence marks for the creation of inert fingerprints on the glass. Iodine fume, financially accessible 502 cyanoacrylate stick fume and TiO2 were discovered to be inadequate in creating dormant fingerprints on the glass side. The erosion edges of the fingerprints were hard to recognize from the foundation. fluorescent starch can be utilized as a successful powder for the advancement of inert fingerprints, with sharp edges, better goal, and less foundation obstruction, because of their improved solid blue iridescence. To analyse the affectability of the over four strategies, a progression of identifications on different substrates were performed. Iodine-fume, economically 502 cyanoacrylate stick fume, and Titanium oxide powder both have lower affectability than fluorescent starch powder.

The CNP-based nanocomposites had truly stable compound properties and tuneable photoluminescent results, and were effectively utilized as a novel fluorescent name for the creation of idle fingerprints on different substrates, demonstrating moderately all around created qualities for finger edge data and great differentiation for improved location. The investigation presents a novel technique for producing whole inactive fingerprints utilizing CNPs in the legal sciences.[6,3]

Silicon Oxide Nanoparticles

Silicon Oxide Nanoparticles are one of a couple of nanoparticles with the entirety of the attributes for inert finger-mark location and improvement. The reversed micro-emulsion method can be used to make SiO2 NPs with a uniform size distribution. During the combination of SiO2 NPs, profoundly brilliant colour atoms can likewise be typified in the centre. It has been demonstrated in the literature that SiO2-based NPs can be used to detect latent finger marks.

In this method Triton X-100 (TX-100), 1-hexanol, ammonium hydroxide (30%), tetraethyl orthosilicate (TEOS), tris(2,20-bipyridyl) dichlororuthe- nium(II) hexahydrate (RuBpy) and sodium chloride (NaCl) were used . With the exception of the NP precipitation, silver oxide nanoparticles were synthesized using the reversed micro-emulsion technique stated by Moret et al.19. Here's a quick rundown of the synthetic technique. In a round bottom flask, 3.54 mL TX-100, 15 mL cyclohexane, and 3.6 mL 1-hexanol were inserted, followed by 960 mL RuBpy (16.6 mM), 200 mL TEOS, and 120 mL ammonium hydroxide (30 percent). For surface functionalization, 100 mL of TEOS and 100 mL of CES were mixed to the response combination following 24 hours of constant attractive blending.

For another 24 hours, the mixture was stirred. To start the precipitation of the NPs, the miniature emulsion blend was moved to a hawk axis cylinder and 20 mL of acetone was applied to it. The nanoparticles were secluded by centrifugation at 2500 RPM for 3 minutes, followed by decantation of the acetone. The isolated NPs were then treated with 15 mL of acetone. The nanoparticles were shaken in a falcon rotator tube with a vortex blender, and at that point centrifuged at 2500 RPM for 3 minutes until the acetone was tapped. Finally, RuBpy-doped CES-SiO2 NPs (0.1 g) were collected and dispersed in 20 mL RO/DI water.

Now the collected nanoparticles were used on the finger-marks obtained from different individuals. The finger-mark specimens were divided into two halves. All the finger-marks were treated with SiO2 and depending upon the age of finger marks (3 months old and 7 days old) were divided into different batches. Total 288 finger-marks were taken into account and analysed.

Though the bunch-to-group change from the examination study was noticed, assessment of the viability of the location of finger signs by changed identification boundaries would not be

influenced, as all fingerprints were handled and assessed in the significant half-finger marks. There were noticeable differences between the three donors from the results collected. However, there were improvements in the detection efficiency of three donors with regard to changed detection parameter. [17,3]

DISCUSSION

Technology in forensic science is improving day by day. And nanotechnology has played a major role in the field of fingerprints as they are enhancing the production. Some of the nanotechnology techniques are cost-effective as well as eco-friendly. For example, in red-emitting CaTiO3: Pr3+ nano phosphoric technique, the marks produced from this method can be maintained for longer periods of time. Because of their promising benefits and consistency of performance, nanoparticles have surpassed traditional methods.

CONCLUSION

Nanotechnology helps forensic science in two respects. Since it can identify and analyze samples at the nanoscale, vital information that could not previously be obtained and examined due to limitation of instruments can now be analyzed and used to support investigations. Due to its various advantages, nanotechnology has also became a branch of forensic science known as nanoforensic. This review summarizes how nanoparticles have created new advancements and branches in the field of forensic science. IJFMP

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Role of Nanoparticles in Latent Fingerprinting: An Update

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Abstract: Nanotechnology is an escalating branch whose feelers are mesmerizing nearly every field of science. It is the evolving field in forensic science, the advancement of emergent techniques of nanoparticles being unified with latent fingerprinting. The size of nanomaterials made them unique and have adjustable mechanical, electrical, and optical properties. At the crime scene, the prints that are left behind are generally latent (invisible) fingerprints. The Current review paper encompasses the synthesis of nanoparticles from conventional and advances synthetic pathways. Their applications, with and without modifications and their impacts on the enhancement of latent fingerprints, have also been discussed.

Keywords: Nanoparticles; latent prints; fingerprints; nanopowder; crime scene; evidence.

1. Introduction

Nanotechnology is one of the advanced branches of science that is focused on nuclear, sub-atomic, and supramolecular particles planning to make nanostructures with improved functionalities [1]. The term nanoparticle depicts particulate issues running in size from 1–100 nm [2]. Nanotechnology is an escalating branch whose feelers are mesmerizing nearly every field of science. With the improvement of nanotechnology, it has been found nanomaterials are generally utilized in criminological sciences for investigation and testing. Nanotechnology is the evolving field in forensic science, the advancement of emergent techniques of nanoparticles being unified with latent fingerprinting. The size of nanomaterials made them unique and have adjustable mechanical, electrical, and optical properties [3]. Their size correspondingly permits them to have a brilliant and large reactivity and offers the capability to be modified by an innumerable of functional agents. The nanostructures aids in the detection and expansion of latent fingerprints. Different nanoparticles such as Si, C, Al, Cu, Ba, Fe, V, Au, and Ag have been industrialized to obtain latent fingerprints. The general and individual characteristics of fingerprints and other minute details like the position of pores are enhanced by nanoparticles.

In general, at the crime scene, the most common but invisible evidence left behind is the fingerprints of the suspect as well as of the victim. These fingerprints give almost exact verification of the presence of a person at the crime sight, as every human being has a unique pattern of a fingerprint. These fingerprints can be easily distinguished based on their dissimilar ridges and patterns. Fingerprints obtained due to the sweat secreted by the glands named as eccrine and apocrine existing on the fingers. Although these glands are present throughout the body and responsible for the secretion of sweat, help in leaving the traces of invisible prints at

the scene of crime due to the presence of ridges and whorls present on fingerprint during the process of deposition [4]. Fingermarks, consisting of water, amino acids, fatty acids, and minerals, could be defined as imprints of regions left on a surface of friction ridge skin through different analytical methods [5].

Powder dusting method is the earliest technique used to develop invisible fingerprints [6,7], which is still a preferable one at the crime scene as it is cost-effective, easily available, and ease in use. However, the traditional powder-dusting method has some disadvantages in terms of low sensitivity, less contrast, toxic in nature, and high autofluorescence intrusion. Therefore, to overcome these disadvantages and to get more accurate and precise results to use of nanoparticles has come into practice as a better choice. In the same direction, various researchers and scientists contributed by developing nanoparticles, studying their exploitation in the enhancement of invisible fingermarks with better character development.

2. Methods

Since now, many different types of nanoparticles have been synthesized and exploited in latent fingerprinting such as Aptamer- functionalized core-shell nanoparticle, Iron Oxide Nanoparticles, etc. They have been found to have different results in fingerprints applications, as discussed below:

2.1. Aptamer- functionalized core-shell nanoparticle.

The Aptamer is an oligonucleotide that is short in length and single-stranded in nature. Owing to have such characteristics, this oligosaccharide can be mold into a 3-D structure in the existence of target to apprehend precise recognition these unsurpassed properties, like easy modification in structure, high affinity, and specificity, flexible design, biochemical stability, slightly synthetic make Aptamer, a very good choice to be used in latent fingerprint development. These carbohydrate molecules easily get bonded with lysozymes, a universal compound present in human sweat [8].

A lysozyme binding aptamer modified structure by fusing Au/PNTP / SiO_2 and studied them using surface-enhanced Raman scattering (SERS). The study revealed that specific molecules (PNTP) implanted amongst the gold core and the shell of silica were effective in evading the interference of the external environment. This helped in determining the reproducibility and stability of SERS indicators. In accumulation to that, the free surface of the silica shell could be modified with Lysozyme Binding Aptamer (LBA).

Zhao *et al*., 2016 [9] used Fren's method to prepare Au nanoparticles [10], Synthesized Au nanoparticles, and Au/PNTP / SiO_2 lysozyme binding aptamer nanoparticles have been characterized using the transmission electron microscope, Raman spectroscopy spectra were measured using UV- Visible spectrophotometer. Modified sandwiched SERS probes have been used to effectively detect the developed and recorded latent fingerprints from the glass surface, results obtained revealed that these nanoprobes might easily be placed on the ridges of fingermark and recognized at all the three levels, pattern, individual characteristics, and pores in fingerprints were visible using these nanoparticles [11].

Fingerprints are a shred of important evidence. At a crime scene, usually latent prints are present. To develop these prints, the most common method is the powder- dusting technique, a traditional method [12]. It has low sensitivity, background interference, low contrast. The need for alternative methods leads to the development of many other alternative

techniques. Nanoparticles played an important role as one of the alternative techniques. Fluorescent nanoparticles (NPs) like upconversion nanoparticles (UCNPs) and quantum dots (QDs) have a great property which helps in developing latent fingerprints with better sensitivity and contract since it has some exceptional properties like large surface area, high fluorescent intensity, small particle size, and photochemical stability [13, 14, 15, 16, 17].

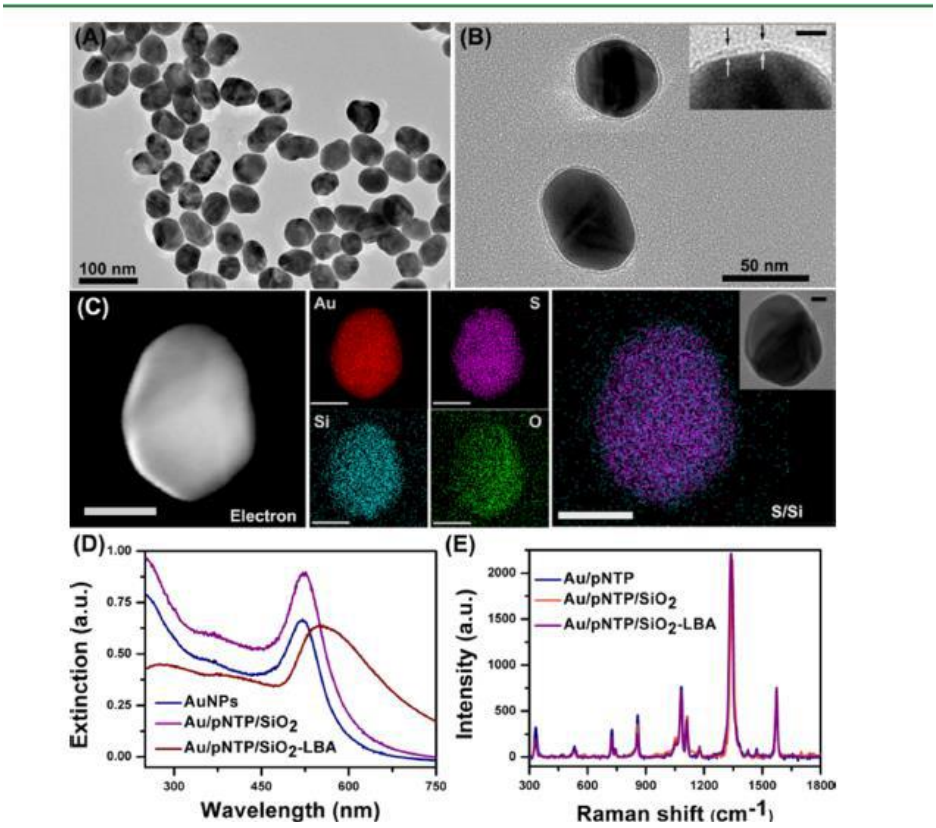

Figure 1. The Transmission electron microscopy pictures of a) Nanoparticles of gold b) Gold /pNTP/Silicon Dioxide SERS nanoprobes c) STEM images of NPs (Au/pNTP/SiO2) using electron, Gold, Sulphur, Silica, and Oxygen signals and the STEM photographs (superimposed image) of Sulphur and Silica. (D) Extinction spectrum of Au/pNTP/SiO_2 SERS nanoprobes (purple line), pure Au NPs (navy line), and Au/pNTP/SiO_2-LBA SERS nanoprobes (red line). (E) SERS spectrum of Au/pNTP/SiO_2 SERS nanoprobes (orange line), pNTP-functionalized AuNPs (blue line) and Au/pNTP/SiO_2-LBA SERS nanoprobes (violet line) [9]. Reprinted with permission from https://doi.org/10.1021/acsami.6b03352. Copyright (2016) American Chemical Society.

Using of UCNPs showed a better result than any other nanoparticles, they can convert the long wavelength radiation into shorter wavelength emission by the mechanism of multiphoton [17, 18, 19, 20, 21]. These nanoparticles get excited by near-infrared light to release strong visible fluorescence. Hence, with the help of UCNPs, sensitivity, and contrast-enhanced, and also remove the interference of the background while detecting the latent fingerprints.

On the contrary, quantum dots uses ultraviolet radiation, which results in the fluorescence of substrate and substantial autofluorescence interference [22, 16, 23 24, 25]. Whereas in UCNPs the use of Near-Infrared radiation to discharge visible light avoids the autofluorescence interfering by the substratum. Fingerprints do contain DNA, which is safe under NIR radiation and is not as much injurious to the eyes and skin of the handler than the UV light. $NaYF_4$: Yb, Er[39], and YVO_4: Yb, Er[40] upconversion luminous particles can be used on invisible fingermarks for its development, on numerous semi-permeable and impermeable

surfaces and the solution is commercially available for use. Due to the non- uniform size and shape, less dispersion and size fluctuating between ~0.2 to 2 μm leads to the reduction of affinity between the fingerprint's residues and particles and decreased detection sensitivity. A research done by Wang *et al*. on nano particles of $NaYF_4$: Yb, Er to checked the working of the particles with lysozyme-binding Aptamer for lysozyme recognition in the fingerprint residues for latent fingerprints detection. This technique confined complex steps and was impractical to use at the scene of crime since it needed the modification in the chemical of upconversion nanoparticles (~260 nm) by complicated measures. The gestation of finger impressions was for 30 mins in UCNPs solution.

Another method developed by Wang *et al*. designed for the fusion of $NaYF_4$: Yb, Er fluorescent upconversion nanoparticles (UCNPs) using the oleic acid-based solvothermal method with the maximum conceivable fluorescence strength beneath near-infrared (NIR) treatment [26]. The factors like volume, time, optimization, and reaction temperature of oleic acid have been studied for the composition phase, and size, and intensity of the UC fluorescence of the upconversion nanoparticles [20]. The subsequent UCNPs have been used to fluorescently label the fingerprints as there might be a chance of UCNPs release the visible light if the excitation of near-infrared light reached to 980 nm. The Dormant fingerprints were examined on significant sorts of even substrates, incorporating with a solitary foundation shading (white clay tiles, black marbles, and transparent glass), various foundation hues (marbles contained composite surface designs), and solid foundation autofluorescence (note, Chinese money, and plates made up of plastic). These results were equated with the traditional powder dusting methods that resulted that UCNPs showed better sensitivity, good contrast quality, less autofluorescence interference, and low background inference. Hence, this research showed that upconversion nanoparticles incorporated beneath upgraded conditions are an adaptable fluorescent marker for the effortless advancement of finger impressions and can locate their handy applications in criminological science[27].

2.2. Iron oxide nanoparticles.

Iron oxide nanoparticles stick to the ridges of fingerprints that help in the visualization of invisible finger impressions [28]. It has the capability of size modification to a different color varies as for un-annealing it showed black, and for annealing, it is brown. The powder form of nanoparticles has been used, which helped in the development and recognition of invisible finger impressions due to the physical affinity with fingermark deposits like sebum, sweat, and other contaminants. Annealed and unannealed iron oxide nanoparticles were synthesized by a green pathway, characterization has been done by XRD, and the purity of nanoparticles was confirmed by EDAX measurement [29]. Latent finger impressions were developed on permeable and impermeable surfaces (glass) [30]. The result showed better-developed fingerprints on the absorbent surface as compared to the non-absorbent surfaces [31 32].

2.3. Carbon dot-based nanopowders.

A highly rapidly developing class of nanoparticles made from carbon (C dot), behaved as high-performance nano emitters showed strength for bioimaging, multicolor printing, catalyst, and act as sensors. C- dots are synthesized by a green pathway, which helped in making it cost-effective. They're biocompatible in nature and non-toxic to the environment and

humans. C- dots improve the colloidal stability and enhance the fluorescence intensity. Because of the tendency of the pure sort of c- dots to aggregate in powder form and according to the reports, the c dots powder isn't photoactive because of wide-ranging clustering and metallurgical properties. Thanks to this tendency of c-dot, a hybrid nanopowder is ready to possess an occasional concentration of it and a serious portion of titania, silica, laponite, and white fingerprint powder. This helped within the flowability of powder and unique photoluminescent ofc- dots. The ridge patterns are visible using the hybrid nanopowder. The fingerprints developed shows some tuneability in color as in reflex to the incident beam wavelength. This showed the blue, green, or red appearance of the fingerprints once excited within the violet, blue, and green wavelength regions, respectively [5].

Similarly, the patterns of color were attained, consuming 0.7wt% c-dots laponite of fingerprints left on metal and glass surfaces. In contrast, the detection of any kind of signals was not observed when c-dots was absent in another experiment. Using C-dot nanopowder, fingerprints were developed on beverage bottle foil that showed deprived contrast underneath high field radiance, and only faded patterns of ridges were visible underneath the green light. At an equivalent time, the better-developed features were determined under violet and blue radiation [33].

2.4. Cu^{2+} engrafted $MgAl_2O_4$ nanoparticles.

The synthesize of Cu^{2+} engrafted $MgAl_20_4$ Nanoparticles have been done by the combustion method using chelating ligand Triethanolamine. The characterization was done by TEM and XRD methods, and the optical property has been checked by UV-DRS method. Magnesium showed photocatalytic activity, which helps in enhancing the latent fingerprints under UV light by brush method. The latent fingerprints were developed and enhanced by applying the powder onto the even surfaces like metallic and lead crystal and later on visualized under UV light at 254 nm. The quality of enhanced prints was not good; the individual characteristics and pores were not visible [34].

2.5. Calcium Molybdate nanophosphors.

Metal Molybdates has a property of transferring the energy from the host lattice to the small ions, which makes it the one kind of oxide-based substance that owns the brilliant luminescent possessions. The metal molybdate having a space group of 141/a with transparent quality and permits different light range to undergo without showing any changes in the luminescence effect is Calcium Molybdate. This material owns adequate chemical and physical features as related to the other oxide materials. The $CaMoO_4$ synthesis process takes a time of 12h, with the particle size ranges between 1-2 micron. This work developed, a comparatively speed up the production of nanostructures shaped as spherical molded with building blocks of nanoparticles [35]. The optical, structural characteristics have been considered of the Nanopowders, which proficiently detect the invisible finger impression on various surfaces [36]. The portrayal has been done by XRD, SEM, EDX. FTIR. The $CaMoO_4$ was incapacitated with Eu^{3+} and Tb^{3+} ions, and for the recognition of invisible fingerprints, the properties of luminescence have been observed in it. Ridge details in the fingerprints were efficiently detected by it. The latent prints could be observed under visible light with better contrast and less interference of background. Different non-porous surfaces were taken to develop latent fingerprints, i.e., compact disc, glass slide, and stainless-steel cup. Therefore, using phosphor

materials, the invisible finger impressions can be developed and detected on various surfaces. The fingerprints were developed by applying the nanopowder on the surface using a brush. The nanopowder was glued to the ridges of fingerprints, not to the grooves. Hence, it showed the minute ridges and sweat pores as well with good contrast and less interference of background. The presence of oily components and moisture in the latent fingerprints enhanced the affinity of the powder towards it. The calcium molybdate reacts with the minute quantity of amino acids existing in the invisible finger marks with a better affinity toward it. Hence, even after keeping the finger marks in the ambient atmosphere for 9 days, the prints were visible [36].

2.6. SiO_2@LaOF: Eu^{3+} core-shell functional nanomaterials.

Silica is a material that is used in core-shell designed constituents and can adjust the size on its own. The nanoparticles are acted as shells that are coated with the silica leads to the formation of phosphors core-shell that is spherical in shape. With few changes or fabrication in the conditions of the experiment, a non-agglomerated, sphere-shaped element can be prepared. The prepared nanoparticles help to get the enhanced brightness with good resolution and reduction of light scattering. The particular nanoparticles can be used for different applications like anti-counterfeiting, biomedical imaging, and other kinds of display devices. The core-shell nanoparticles as these are rare-earth doped nano phosphors showed some specific features like shrill absorption and line emission in an ultra-violet visible spectrophotometer with a good yield of quantum, having exceptional biocompatibility, no toxicity, stability as a thermal and chemical product is good, elongated life and advanced photostability. The lanthanide ions with trivalent luminescence can simply be unified into the crystal assembly as matrices with fluoride as a host, and even at room temperature, it shows luminescence with high efficiency.

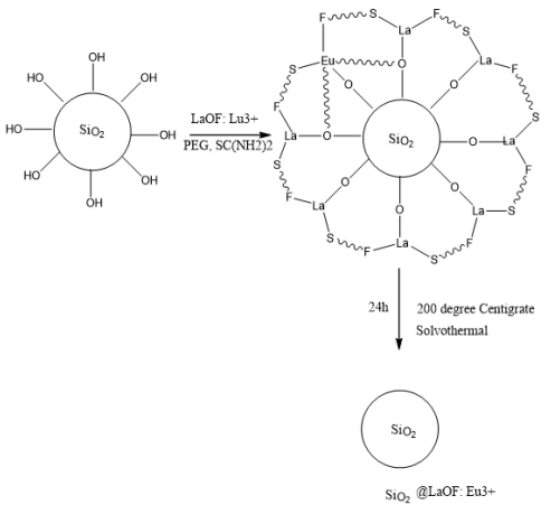

Figure 2. Production of SiO_2@ LaOF: Eu^{3+} shell nanostructure.

Eu^{3+} ions can act as the finest dopant used in numerous hosts for the production of red color discharge, considered as long photoluminescence. The refractive index is higher in these particular nanomaterials. To change or reduce the distance between luminescent and quenching centers of nanomaterials, decrease in the defects of surfaces and reduction of non-radiative channels, surface modification method is one of the utmost accomplished technique to be used. These changes lead to the improvement in luminescent quality in a core-shell nanostructure. Rare-earth doped nanomaterials with not as much of than 100 nm got more consideration as

surface-based research specifically in invisible finger impressions acknowledgment. The characterization has been done by XRD, SEM, TEM, EPR.

Using SiO_2@LaOF: Eu^{3+} nanomaterials, the latent fingerprints were developed on the impermeable surface like scale made up of metal, tin foil, and a stapling device. It was detected the level 2 ridge structures were not visible under white light, but those ridge structures were visible underneath 254 nm Ultra violet rays. The nanopowder was castoff on several absorbent materials like deck cards, covers of a journal notes with background interference observed at 254 nm under UV light, and the ridge characteristics were visible. For the confirmation of fluorescent powders efficiency, different covered composite invisible finger impressions were taken on tin foil surface and stained with SiO_2@LaOF: Eu^{3+} nanoparticles and observed using white light and 254nm ultra-violet light. All the three levels were visible under both the lights that showed the efficiency of fluorescent tagging agent for the imagining of fingerprints. The invisible finger impressions stained on tin foil kept from day 1 to 1 month. After a week, the prints were not evidently visible on the surface [37].

SiO_2 nanoparticles were synthesized for the development of invisible finger impressions on non-absorbent surfaces. The method that was used for the synthesize was reversed microemulsion, where water droplets filled with dye played the role of the microreactor, permitting the growth of nanoparticles [38]. Triton X-100 (TX-100), ammonium hydroxide, Tetraethyl orthosilicate (TEOS), tris(2,20- bipyridyl) dichlororuthenium (II) hexahydrate (RuBpy) cyclohexane, n-hexanol, rhodamine 6G, Carbox- yethylsilanetriol sodium salt (CES) rhodamine B (Dye), sodium chloride (NaCl), and 3-(triethoxysilyl)-propylsuccinic anhydride (TES-PSA) has been used for the synthesizing process. This method has an advantage as it helps in controlling the acute size of the particle, acquaint with dye in the matrix and functionalizing the surface of nanoparticles. After that, nanoparticles were out of the emulsion, and further washed with ethanol and dissolved in water [38]. The characterization was done by dynamic light scattering, laser doppler micro-electrophoresis, and fluorescence spectrophotometer. The fingerprints were taken by three donors (two males and one female) on four different non-porous surfaces (glass, black polyethylene, aluminum foils, and transparent polypropylene)20 samples were taken on each surface by one donor. The prints were developed using SiO_2 nanoparticles that have luminescent properties due to the 3 dyes. The results of the developed prints were compared with the one-step luminescent cyanoacrylate process LumicyanoTM. The fingerprints have been cut into two parts, one part was treated using SiO_2 nanoparticles, and another part was using LumicyanoTM. A correlation with LumicyanoTM, an advanced cyanoacrylate with luminescence, was then led in the direction of a survey to check the productivity of the technique. The two methods were thought about on the arrangement of twenty depletive imprints by 3 benefactors on 4 distinctive impermeable products. All things considered, the two systems performed likewise. Be that as it may, for LumicyanoTM, quality varieties between contributors were watched. Strikingly, that was not watched (or just to a constrained reach out) for SiO_2 nanoparticles. This may be because of the way that the system focuses on a particular practical gathering rather than specific mixes of the emission. The SiO_2 results quality was rather increasingly observed with the category of product. Diverse identification results demonstrated that the strategy stayed to be additionally advanced. The concerning and security problem regarding SiO_2 nanoparticles showed that there was not one lethality evaluation of the blended nanoparticles was acted right now. This ought to be considered in subtleties before any enormous scope application. More work despite everything should be embraced to give a completely operational procedure, yet the revealed

outcomes right now that SiO_2 nanoparticles are extremely encouraging and that examination exertion ought to be additionally sought after [13].

2.7. Aluminum oxide nanoparticles (Al_2O_3– NPs).

The nanoparticles of Aluminum oxide were synthesized using a green pathway with a coating of eosin yellow (dye) and extract of seed. The method was non-toxic and eco-friendly, which helped in the invisible finger impression development. Cyamopsis tetragonoloba seed extract worked as a hydrophobic compound that resisted particles of water and aided the powder particles to stick onto the greasy substance of the invisible finger impressions. This helped in giving better visibility of prints on numerous non-porous and porous surfaces. This also helped in the identification of faded latent fingerprints [32].

2.8. Dual-channel emitting optical probe of Nd^{3+}-sensitized upconversion nanostructure.

The nano phosphors synthesized using Lanthanide upconversion are beneficial to use in various fields, as it helps in reducing the fluorescence interference in the background and high signal to noise ratio of upconversion luminescence. The Nd^{3+}sensitized $NaYbF_4$: Tm@$NaYF_4$:Yb@$NaNdF_4$: Yb graded designed nanoparticles emits near infra-red rays, and at 696 and 980 nm, its luminescence and excitation occurred at 808 nm [39]. The $NaYbF_4$ core endorses effective zeal transmitted towards Tm^{3+}. The interlayer of $NaYF_4$: Yb effectively averts the process of cross-relaxation from Tm^{3+} to Nd^{3+}. Therefore, it helped in improving the production of luminescent property. The Nd^{3+} helped in the alteration of wavelength excitation from 980 to 808nm.

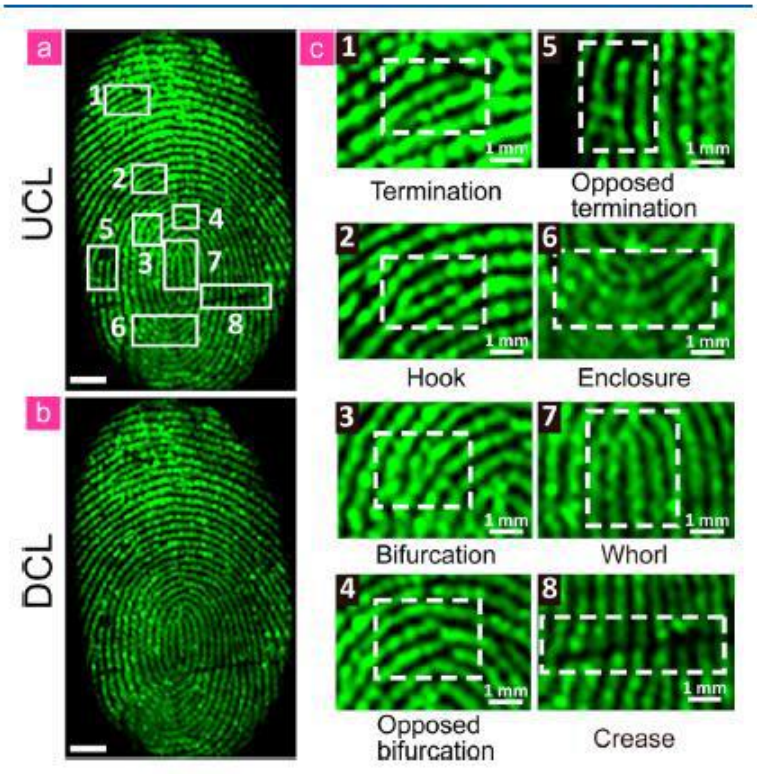

Figure 3. Stokes and UCL discharge pictures (a, b) of finger impression on the surface of polyethylene baggage. (C)distended UCL images of fingerprints showed (1) termination, (2) hook, (3) bifurcation, (4) divergent bifurcation, (5) divergent termination (6) enclosure, (7) whorl, (8), and crease at 808 nm[39]. Reprinted with permission from https://doi.org/10.1021/acs.inorgchem.6b01536. Copyright (2016) American Chemical Society.

The thermal effect has been faintly deterred induced by laser and leads to a new way for the secretion way of near infra-red rays at 980nm. The developed nanoparticles were used for invisible fingerprints and for bloody fingerprints image development, which showed details distinctly beneath 808nm excitation and exhibited a huge signal to noise ratio with zero thermal damage to the fingerprint sample. These kinds of nanoparticles can be used in forensic applications for better enhancement of prints [39].

2.9. Use of N-doped carbon dots for the imaging of finger impressions.

Polyvinylpyrrolidone (PVP) polymers have been used for the N doped carbon dots synthesis, using the hydrothermal method, which helps in yielding the beaming fluorescent waves when excited at 350 nm. These carbon dots were used for the recognition of finger impressions, and it showed the inimitable characteristics depicted as a clear, bright figure of the fingerprint. Chemical examination of N-doped carbon dots showed that the surface functional group is CeNHe, which contributes as a reason for the biomolecule's interaction with them, which led to the formation of precise fluorescence designs. The fluorescence emanation, initiated from the various fluorophores' designs, depicted three important components present on the N- carbon dots nanoparticles surface. They are non-hazardous in nature if the quantity is about 0.01 mg/mL. In this particular work, the carbon dots were used on two substances as fluorescence tags to image finger impressions: tweezers and on the plastic surface. The result showed satisfactory finger impression images, showing clear ridges in the emission of orange color obtained with the help of filters helped in transmitting the lengthy wavelength to reduce the background contained fluorescence and allowed detailed imaging when illuminated at 360nm. The subsequent copy must be snapped with the help of a filter that illuminates the similar wavelengths as the one castoff for observing [40], for easy comparison and recognition of finger impression minutiae [41].

2.10. Silver nanoparticles.

A practical and easy technique was developed by Qin in 2013 [42] for visualization of latent fingerprints processed by eccrine and sebaceous glands by using silver and gold nanoparticles produced by the electrochemical process. The electrodeposition approach [43, 44] has been used as it only occurs on the valleys present between the ridges of fingerprints and the free conductive surface. This process enhanced the contrast and showed greater advantage as it is a simple, high resolution, non-hazardous, and rapid procedure used in the enhancement of invisible fingerprints on rough, smooth, clean, dirty conductive exteriors performed in aqueous solution hence, appropriate on a damp piece of evidence [45]. Different metal surfaces like stainless steel, platinum were taken, and silver and gold were electrodeposited on the metallic substrate between the elevations of fingerprints. The result showed clear images of invisible finger impressions on clean metal substrates in comparison to the dirty surface.

Due to the affinity of metallic silver towards the organic elements in fingerprint residue, it has been used in the physical developer method as a reagent since 1970. This helps in invisible fingermarks visualization on absorbent shells. The silver physical developer method is based on the oxidation-reduction reaction, where iron salt reduces the silver nitrate to metallic silver in an aqueous solution. The formation of silver nanoparticles takes place during the interaction of organic elements of fingerprint residue leads to the visualization of

fingermark as a black silver image or dark grey on the surface. The development occurs due to the attraction of electrophoresis between the silver colloids (negatively charged) and fingerprint residues (positively charged). For porous surfaces, the silver physical developer method is appropriate as it visualized the prints on the moistened samples. The visibility of prints is not satisfactory. Therefore, before the dealing of prints with a silver physical developer, it has been treated with nanoparticles of gold using citrate ions as a stabilizer [32].

2.11. Zinc Oxide Nanoparticles (ZnO-NPs).

The properties of zinc oxide show high excitation binding energy (60MeV), and wide bandgap (3.37 eV), this helps in the transition of zinc oxide at room temperature and contains an epoxy resin asset which enables the collaboration between the proteins and lipids present as residues of fingerprints on room temperature. Zinc oxide was used in the form of Nanopowders to enhance the old hidden finer impressions on impermeable exteriors. It helped in developing unique ridge details of fingerprints that fluoresced under UV light. According to the research done by Sydney University, Zinc oxide nanopowders develop clear prints as well as fluoresce naturally under UV light in wet conditions. Other studies showed that it also gives better fluorescence image when illuminated under long-wave UV light [32].

Arshad A *et al*. [46] synthesized ZnO-SiO_2 Nanopowder by the conventional heating method using $Zn(CH_3COO)_2.2H_2O$, $Na_2SiO_3.5H_2O$, and NaOH. The characterization has been done by FTIR, XRD, energy dispersive X-ray (EDX) analysis, Scanning electron microscope, and TEM. The size of the particles of ZnO-SiO_2 nanopowder done by TEM was 32.9 nm. The enhancement of dormant finger impressions was done on dissimilar semi-permeable and non-porous substrates such as calculator, board marker, laptop with the help of small particle reagent, and powder dusting methods. SPR method has also been used on damp impermeable substrates. They exhibited clear quality prints with 2^{nd} and 3^{rd} level minutiae of ridges when compared to the commercial powders they gave better visibility and just stick to the ridges, unlike white powder which adhered to all over the surface.

Luthra D *et al*. helped in developing the latent fingerprints by synthesizing new metal oxides nanoparticles (tin oxide and zinc oxide) using chemical precipitation method in the form of dry powder for zinc oxide nanoparticles synthesis zinc acetate and NaOH were taken, and for tin oxide nanoparticles, tin chloride, and NaOH has been used followed by ethanol. The characterization has been done by X-ray diffraction, UV-Visible spectroscopy, and FTIR. The ZnO crystals size remained 14.75 nm, while tin oxide was found to be 90 nm in size. These powders were used on the impermeable substrates like lead crystal, plastic, glossy cardboard, where dormant finger impressions existed, and they developed them. The study showed that Zinc oxide nanoparticles gave clear and better-enhanced fingerprints on all the three surfaces as compared to the prints developed by tin oxide nanoparticles [47].

The development of a latent finger impression on plastic surfaces has been successively done by the Vacuum Metal Deposition method using Au and Zn particles. A streamlined vacuum deposition process was directed to create a unique mark in this investigation. Unadulterated Zinc oxide has thermally vanished in a void framework, Zinc oxide could gather on polyethylene terephthalate (PET) surface. While zinc has been used to create a unique dormant mark in Gold/Zinc vacuum metal deposition, the subsequent Zinc store mostly reacted to Zinc $oxide_{(x)}$ while coming in contact with air or during the deposition of zinc within sight of O_2 [48]. In the interim, consistent Zinc oxide films kept by vacuum dissipation procedures were legitimately covered onto non-metallic substances on different things [49, 50, 51].

Subsequently, it is beneficial to utilize the vacuum statement of ZnO to create a unique mark on plastic surfaces. In this examination, the warm vanishing of ZnO was led to create a unique idle mark on polyethylene terephthalate, deprived of utilizing gold groups as the seed layer. Unique mark improvement on polyethylene terephthalate by Zinc oxide affidavit and Gold/Zinc vacuum metal deposition was thought about. No advancement of a unique mark is seen over polyethylene terephthalate after unadulterated Zn statement, deprived of using gold kernels. The outcome concurred with writing [52], demonstrating a poor testimony capacity of Zn on the plastic surface. The unique finger impression created by the gold/zinc vacuum metal deposition procedure utilizing gold and zinc products displays a solid difference between unique finger impression edges and valleys. The gold/zinc vacuum metal deposition procedure showed a typical improvement of a unique mark in metallic sparkle. Typical improvement with a clear differentiation between unique finger impression edges and valleys is too created by zinc oxide testimony. Dark unique mark is created using zinc oxide affidavit. It showed that Zinc oxide might be straightforwardly kept on the valley amongst unique finger impression edges and the free surface of polyethylene terephthalate. Along these lines, other than solitary metallic vacuum metal deposition [53] using vacuum vanishing of Zinc oxide can likewise create inert finger impressions on the polyethylene terephthalate substrates, lacking earlier smearing a slight coating of gold, and without pre-treatment by cyanoacrylate raging. The zinc oxide developed a clear pattern on fresh samples as compared to old samples. However, the zinc oxide deposition can create a unique preferable mark over gold/zinc vacuum metal deposition on the finger impression, matured for 1 month and 15 days [54].

2.12. Gold nanoparticles (AuNPs).

In the advancement of the dormant finger impressions process, Gold nanoparticles (AuNPs) played a noteworthy job due to their dormant behavior, better discernment, affectability, and qualities, that empower the capacity of the created finger impressions for a drawn-out timeframe [55]. In the multi-metal deposition, the gold nanoparticles were used due to their significant properties, which improve the permeability of the Latent fingerprints by two-advance sol-gel technique. The substrate that has a unique finger impression was absorbed using the gold nanoparticles solution (balanced out in the medium of citrate ion) trailed by the expansion of silver physical developer (Ag-PD solution) [15, 55]. Using a UV-Vis spectrophotometer, characterization has been done. The nanoparticles of gold bound to the residues of finger impressions and mobilize the precipitation of Ag particles to metallic Ag [46, 14, 56]. Due to the electrostatic interaction between the cationic charged finger impression residue and anionic charged Au nanoparticles, a silver picture of the dormant unique finger impression is acquired. Though, the use of the multi-metal deposition technique is constrained as it needs the item having the fingerprints to be washed in a fluid arrangement of the nanoparticles of gold. Consequently, the technique isn't appropriate for building up the prints on surfaces, for example, dividers and floors, or for any item too enormous to ever be absorbed a work area shower. This technique is expensive [32].

Nanomaterials have been used to develop latent fingerprints as it shows better enhancement of latent prints. It increases the superficial interface with the endogenic material present on the elevations, also enhances the disparity and finger impressions. As most of the scientists focused on visualized the fingerprints at a physical level, this paper focused on the exploration of molecular-level information embedded in latent fingerprints. A key trademark is the predominant presentation of nanomaterials in upgrading the affectability as well as

particularity in estimation sciences [57, 58]. When gold metal is nanosized, it shows unmistakable visual characters because of the surface plasmon resonance (SPR) [59]. By altering the size, the shape of gold nanoparticles, a range of blue to red color can be obtained. The interesting property was utilized for detection as a colorimetric, surface-upgraded Raman scattering, and bioimaging. The light of gold nanoparticles with ultraviolet light can instigate quick warming in a little amount of the nanoparticles. The particular character can encourage the proficient desorption/ionization of particles accumulate on the surface of gold nanoparticles. The Nanoparticles of gold have dual properties which have been integrated. The characterization of AuNPs was done by TEM, and imaging of dormant finger impressions was done using the sputtering of gold. The coordination of certain characteristics of nanoparticles made up of gold was performed by imaging mass spectrometry for the depiction and atomic imaging of dormant finger impressions. Two differentiating hues (blue and pink), emerging from diverse surface plasmon resonance (SPR) groups of the gold nanoparticles, uncover the visual pictures of dormant finger impressions. The laser desorption/ionization characters of the gold nanoparticles permit the immediate investigation of endogenic and exogenic mixes inserted in dormant finger impressions and imaging their appropriations lacking upsetting the unique mark designs. The concurrent perception of dormant finger impressions and the account for the atomic pictures give proof on a singular way of life as well as settle covering fingerprints and recognize risky substances. The technique depicted the turn of events of a visual picture of dormant finger impressions in the parched condition. It can save compound data implanted in the unique mark for successive investigation by mass spectrometry. The various types of gold nanoparticles showing diverse surface plasmon resonance characters permit a distinct representation of dormant finger impressions by examination with unaided eyes. The laser desorption/ ionization property of gold nanoparticles makes it a successful mechanism for the straight examination of little particles inside invisible fingermarks and the age of atomic pictures. The reciprocal idea of the twofold pictures of invisible fingermarks, that is, ocular and atomic pictures, gives the physical example of fingerprints for singular ID and uncovers substance data inside fingerprints for scientific examinations. The gold nanoparticles electrical conductivity recently revealed by examining under the scanning electron microscope (SEM) for the examination of fingerprints at minuscule scale, that the AuNPs could go about as a viable mechanism for crossing over various imaging methods from plainly visible to infinitesimal (Scanning electron microscopy assessment) stages and uniform to atomic examination (mass spectrometric imaging) [60].

2.13. Oligomer/silica hybrid nanoparticles.

The red-emissive silica nanoparticles were synthesized by doping it with conjugated Oligomer Fluorescence Dioxaborolane Benzothiadiazole (OFDBT), which displayed an auspicious act on imaging of invisible finger impressions. The epoxy groups played a significant part in the preparation procedure because of its morphological and optical properties, as compared to the hydroxyl or amino groups modification. Three types of nanoparticles were developed using epoxy, amino, and a hydroxyl group. The Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silica Oxide-Epoxy nanoparticles were organized by the reverse micelle method using APTMS as one of the compounds, and the ultimate product was obtained by freeze-drying in the form of pink color powder. The Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon dioxide-OH nanoparticles were also prepared by reverse micelle method using silane as a component, collected by freeze-drying in

the form of red powder. The synthesis of Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-NH_2 nanoparticles was also alike to the process of Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-Epoxy nanoparticles but using 3-aminopropyl trimethoxy silane instead of 3-glycidyloxypropyl trimethoxy silane, and the concluding product was obtained by freeze-drying as pink powder. The characterization of nanoparticles has been done by DLS, Scanning electron microscope, NMR, MALDI, ultra-violet visible spectrophotometer. The Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-Epoxy nanoparticles displayed a sphere-shaped of 20 nm in size, useful to intermingle with finger impressions elevations through the mechanical procedure. The quantum yield and photostability of Oligomer Fluorescence Dioxaborolane Benzothiadiazole were amended expressively, due to the property of molecularly dispersing property of silica nanoparticles. The attained Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-Epoxy nanopowder exhibited kinship towards the emissions of the fingerprint's material, formed the pictures with fluorescence characters with enhanced firmness and features with detailing in it.

The stability of the nanoparticles with better sensitiveness showed a great visualization of dormant fingermarks in an image. The Oligomer Fluorescence Dioxaborolane Benzothiadiazole /SiO_2-OH NPs showed sphere-shaped particles of 42nm size, but there was no clear accumulation because of the feeble collaboration of nanoparticles and insolvent such as water. The asymmetrical shapes of these nanoparticles were noticed, which occurred due to the excess number of amino groups. Similarly, the size distribution was detected in water using dynamic light scattering. The size of Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-Epoxy nanoparticles was around 25nm. In contrast, the other set of nanoparticles exhibited a wide range in size with a peak of almost 280nm. The hydrodynamic sizes of Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-OH nanoparticles and Oligomer Fluorescence Dioxaborolane Benzothiadiazole Silica nanoparticles were measured to be about 50 and 120 nm, respectively. They showed comparable outcomes with scanning electron microscopy result outcomes. The light microscopy and fluorescence microscopy outcomes also established the propensity of accumulation below the parched condition of OFDBT/Silicon Dioxide-Epoxy nanoparticles. In contrast, Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-OH nanoparticles were additionally single spread, and the bulky amount of powder was detected in Oligomer Fluorescence Dioxaborolane Benzothiadiazole / Silicon Dioxide-NH_2 nanoparticles.

To affirm the association type, the invisible finger impressions kept on lead crystal was submerged in H_2O for twenty minutes and sixty minutes, at that point, created by the 3 sorts of nanoparticles. Nearly hydrophilic substrates may be liquified inside the drenching in H_2O, and further expelled as submersion time expanded. The relating imaging outcomes illustrated that every last one of the ocular and fluorescent fingermarks pictures created by the 3 nanoparticles indicated all around settled fingermarks over the lead crystal. At the point when the finger impressions were inundated in H_2O for twenty minutes, and sixty minutes, the fluorescent pictures created by Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-Epoxy nanoparticles just demonstrated a small decrease inside the fluorescent force, and distinct finger impressions with better contrast were detected. A considerable modification was seen as the aftereffects of Oligomer Fluorescence Dioxaborolane Benzothiadiazole /Silicon Dioxide-OH nanoparticles. An unmistakable decrease in fluorescence signal was observed

after twenty minutes inundation, and a blurred unique finger impression was detected after sixty minutes of submersion, which was hard to see by unaided eyes. The outside of OFDBT/Silicon Dioxide-OH nanoparticles was very hydrophilic due to the existence of plentiful hydroxyl sets. Its hydrophilic cooperation with the H_2O-dissolvable segments inside the unique fingermark edges had a significant impact. In the case of OFDBT/Silicon Dioxide-NH_2 nanoparticles, the quality of images additionally diminished with inundation time, and colossal totals showed up after a more drawn out submersion process. Taking into account that most of the biomolecules having anionic charges[61, 62, 8], the nanoparticles having cationic charges may require a powerful association with them. In this manner, both of the OFDBT/Silicon Dioxide-Epoxy nanoparticles and OFDBT/Silicon Dioxide-NH_2 nanoparticles demonstrated less experiencing the H_2O inundation. Moreover, the OFDBT/Silicon Dioxide-Epoxy nanoparticles demonstrated a greater bond with the finger impression edges than OFDBT/Silicon Dioxide-NH_2 nanoparticles, showing the epoxy bunches additionally added to the high proclivity towards the finger impressions [63].

3. Conclusions

Forensic science has many branches and deals with different pieces of evidence which helps in getting the criminal identity, among them fingerprint is one of the significant pieces of evidence when it comes to finding the essential lead regarding the suspect. Fingerprint depicts the individual as fingerprints are unique; no two individual shares the same fingerprints. Apart from the characteristics of the fingerprints are enhanced with proper techniques, one can extract the DNA from it. The nanoparticle development method enhances the latent prints in a better way. By doping the nanoparticles with other compounds such as n- doped carbon dots, Silica Oxide @LaOF: Eu^{3+} core-shell functional nanoparticles lead to enhancement of finger impressions with all the details in it like individual and class characteristics, and location of pores. The exploitation of nanoparticle in latent fingerprinting provided a different direction for forensic investigators. These nanosized particles, when used as a developmental method in the latent fingerprinting, reflect numerous advantages over conventional methods. These particles can easily be employed to reveal fingerprints on various surfaces and has excellent potential for envisioning of finger ridge detailing in a more precise way. This reflects the better discernibility of nanoparticles over commercially available conventional materials used for fingerprinting.

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Conflicts of Interest

The authors declare no conflict of interest.

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Manson, P.; Bleay, S.; Vetrone, F.; Capobianco, J.A.; Fouad, O.A.; Ismail, A.A.; Zaki, Z.I.; Mohamed, R.M.; Becue, A.; Champod, C.; Margot, P.; Mobaraki, A.; Hosseinzadeh, Z.; Yavari, I.; Yu, I.H.; Jou, S.; Chen, C.M.C.; Wang, K.C.; Pang, L.J.; Liao, J.S. Lanthanide-Doped Fluoride Nanoparticles: Luminescence, Upconversion, and Biological Applications. *Forensic Sci. Int.* **2011**, *22*, 5808–5829, https://doi.org/10.1021/acs.analchem.5b03010.

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58. Wilson, R. The Use of Gold Nanoparticles in Diagnostics and Detection. *Chem. Soc. Rev.* **2008**, *37*, 2028–2045, https://doi.org/10.1039/b712179m.
59. Ni, W.; Kou, X.; Yang, Z.; Wang, J. Tailoring Longitudinal Surface Plasmon Wavelengths, Scattering and Absorption Cross Sections of Gold Nanorods. *ACS Nano* **2008**, *2*, 677–686, https://doi.org/10.1021/nn7003603.
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Author's Bio-Data

KAJOL BHATI

AREA OF SPECIALIZATION

Forensic Biology, Serology, DNA Profiling, Fingerprints, Documents

KEY SKILLS/ QUALITIES

- An enthusiastic person, highly motivated, and eager to learn new things.
- Strong attention to detail
- Strong motivational and leadership skills.
- Good communication skills and good with computers.
- Quick learner
- Persistent Problem Solver
- High-level accuracy
- Ability to work as an individual as well as in a group.
- Microsoft Office Programs
- Editing copy
- Technical Writing
- Trained in serology and D.N.A. isolation techniques.
- Trained in Document examination.

MY EXPERIENCE

ASSISTANT PROFESSOR

Galgotias University| Dec 2018 - Present

- For B.Sc. & M.Sc. Forensic Science
- Departmental Social Media Coordinator
- Departmental Event Coordinator
- Faculty Club Head of Actors Hub, University Club.
- Project mentor of graduate students.
- Committee member of "Agora" Forensic Society of Galgotias University

ASSISTANT PROESSOR

Jain University | Oct 2017 - Nov 2018

- For B.Sc. Forensic Science
- Committee member of Women Development Cell in School of sciences
- Committee Member of 'Crestas', cultural forum of forensic science.

Guest Lecturer

Dept of Anthropology, University of Delhi| July 2017 - Sept 2017

- Guest lecturer for M.Sc. Forensic Science.
- Efficiently delivered lectures on Forensic Science unit, forensic physics, Forensic Biology and impression evidences.

Scientific Officer

Premier Forensic Science Institute, New Delhi | July 2016 - Dec 2016

Profile- Examination of documents, CCTV camera footage examination and Fingerprint Examination.,

MY EDUCATION

PhD Forensic Science (Pursuing)

Galgotias University| Enrolled -2019

Area of Research- Nanoparticles and fingerprints

M.Phil (Physical Anthropology)

Dept. of Anthropology, University of Delhi | 2016 - 2018

Area of research- Forensic Odontology
- Wrote a thesis on the topic of Dental Age Estimation in Two Population Groups of North India Using Demirjian's Method..

M.Sc. Forensic Science

LNJN NICFS, GGSIP UNIVERSITY | 2014-2016

Specialization in Forensic Biology, Serology and DNA Profiling.
- Wrote a dissertation on the Study of Diatoms from water samples of different water bodies located in Delhi region.
Minor Project on Comparative study of preliminary test of blood on washed stained clothes.

B.Sc. Life Sciences

Gargi College, University of Delhi | 2014

FELLOWSHIP AND AWARDS

- National Eligibility Test (NET) for Lectureship in Forensic Sciences by UGC, India (December, 2015)
- Non-NET Fellowship for M.Phil., Department of Anthropology, University of Delhi, India (August 2016-August 2017)

CORE STRENGTHS

- Willingness to learn.
- Positive attitude.
- Sincere.
- Punctual.
- Effective Communicator.
- Motivated Team Player.
- Management Skills
- Technical skills
- skilled data collection

TECHNIQUES KNOWN

- Thin layer chromatography
- Gel electrophoresis
- DNA profiling
- PCR
- Southern blotting
- Powder and chemical methods for detecting latent fingerprints
- Blood Grouping Methods
- Extraction Method for Drug analysis
- Ouchterlony method
- UV-Spectrophotometric instrumentation

CERTIFICATE COURSES

- Certificate Course: Graphology Fundamentals by Likhavat Academy, Skill India.
- Certificate Course: Forensic Accounting and Fraud Examination by West Virginia University is offered through Coursera.
- Certificate Course: Gene Therapy by The Open University U.K
- Certificate Course: Forensic Science and Fingerprints by The Open University U.K
- Certificate Course: Introduction to Python
- Certification course: Human Molecular Genetics, NPTEL
- Certificate of Excellence: Research data Management by Elsevier, Research Academy
- Certificate of Excellence: Writing Skills by Elsevier, Research Academy

PUBLICATIONS

- **Bhati, K.**, Tripathy, D. B., Dixit, A. K., Kumaravel, V., Sabir, J. S., Rather, I. A., & Shukla, S. (2023). Waste Biomass Originated Biocompatible Fluorescent Graphene Nano-Sheets for Latent Fingerprints Detection in Versatile Surfaces. Catalysts, 13(7), 1077.
- **Bhati, K.**, Bajpai Tripathy, D., Kumaravel, V., Sudhani, H. P., Ali, S., Choudhary, R., & Shukla, S. (2023). Sensitive Fingerprint Detection Using Biocompatible Mesoporous Silica Nanoparticle Coating on Non-Porous Surfaces. Coatings, 13(2), 268.
- **Bhati, K.**, Tripathy, D. B., & Gupta, A. (2023, February). Acridine as Bioinspired Corrosion Inhibitors. In Macromolecular Symposia (Vol. 407, No. 1, p. 2200106).
- Tripathy, D. B., **Bhati, K**., & Gupta, A. (2023, February). Role of Surfactants Against Covid-19: A Scientific Approach. In Macromolecular Symposia (Vol. 407, No. 1, p. 2100415).
- Walia, M., **Bhati, K.**, & Gullaiya, J. (2023). Application of Dental Age Estimation: A Review. Research Journal of Pharmacy and Technology, 16(5), 2513-2516.
- Chhabra, P., **Bhati, K.**, & Yadav, S. (2022). Sexual Offences: Recent Methods of Investigation. In Crime Scene Management within Forensic Science (pp. 155-183). Springer, Singapore. https://doi.org/10.1007/978-981-16-6683-4_7
- Chhabra, P., & Bhati, K. (2021). Bionanomaterials: Advancements in Wound Healing and Tissue Regeneration. In Recent Advances in Wound Healing. IntechOpen. DOI: 10.5772/intechopen.97298
- Bhati, K., Chhabra, P., Sawhney, S., & Gupta, U. (2021): Comparative Study on touch DNA Extraction method, Indian Journal of Forensic Medicine and Pathology

- **Bhati, K.,** Tripathy, D. B., & Chhabra, P., (2021): Role of Fluorescence Substances in the Development of Latent Fingerprints: A Review, Indian Journal of Forensic Medicine and Pathology.
- Johri, A., **Bhati, K.,** Chhabra, P. Bio-Polymeric Nanoparticles for Prospective Forensic Applications: A Futuristic Approach. Indian Journal of Forensic Medicine and Pathology. Volume 14 issue2 Apr-Jun 2021.174-180.
- Sawhney, S., **Bhati, K.,** Tripathy, D. B.& Chhabra, P. (2021): Role of Nanotechnological Techniques in Fingerprints Enhancement: A Review, Indian Journal of Forensic Medicine and Pathology
- Anirud, Bhati, K. (2021): Understanding the Psychology of Paraphilic and violent offenders, Indian Journal of Forensic Medicine and Pathology.
- Kumari, M., Tripathy, D. B., **Bhati, K.**, Gupta, A., & Sharma, S. (2020). The landscape on the metal analysis in green vegetables: A review. Journal of Natural Remedies, 21(8 (1)), 67-79.
- **Bhati, K.,** Tripathy, D. B., & Gupta, A. (2020). Gemini Imidazolinium Surfactants: A Versatile Class of Molecules. In Colloids-Types, Preparation and Applications. IntechOpen.
- **Bhati, K.,** Tripathy, B. D. (2020). Role of nanoparticles in fingerprints: An Update. Letters in Applied BioNanosciences,
- **Bhati, K.,** & Walia, M. (2019). Diatoms Databank for Delhi, India: Forensic Identification of Diatoms Based on Morphology. Think India Journal, 22(17), 484-494.
- Walia, M., & **Bhati, K**. (2019). A Review on Diatom Mapping in India: Forensic Identification of Diatoms Based on Morphology. Think India Journal, 22(16), 3511-3528.

PATENTS

- Shruti Jindal, Vinny Sharma, Zamir, Shyam Narayan Singh, Dr. Rajeev Kumar, **Kajol Bhati**, Anurag Mishra (2023): AI Forensic Palynology: An Artificial Intelligence Tool, Application No-202311035607, Patent Office- IN
- **Kajol Bhati**, Dr. Kuldeep, Dr. Subhlaxmi Pradhan Divya B. Tripathy, 4. Dr. Priyanka Chhabra, Dr. Rajeev Kumar (2022). Design of Toothbrush, No- 124606, Patent Office-IN
- Divya B. Tripathy, T. Raghunathan, A. Pandey, V. Santhosh, **K. Bhati,** R. Kumar, P. Chhabra (2022): Benzoylation of Coconut Inflorescence Fiber towards the development of Sustainable Composite Materials. IN Patent, Application No- 202241053351

WORKSHOPS, CONFERENCES & SEMINARS

- 2023: One-week National Level Faculty Development Program “Cloud Infrastructure (AWS)” organized by Manipal University, Jaipur, India, Held on 21-25 August 2023.
- 2023: Five-day Professional Development Program “Outcome Based Education and Innovative Teaching” organized by NITTTR, Chennai, India, held 17-21 July 2023.
- 2023: Fifteen-day Faculty Development Program “Entrepreneurship and Small Business Development” organized by NIESBUD, Ministry of Skills and Development and Entrepreneurship, Govt. of India, held on 13-25 March, 2023.
- 2023: Five-day Faculty Development Program “Interdisciplinary Aspects of Life Sciences for Translational Research: Opportunity and Challenges" organized by Division of Life Sciences, Department of Biosciences, SBAS, Galgotias University, India, held on 24-28 January 2023
- 2022: Five-day Faculty Development program "Emerging technologies and teaching pedagogies in Forensic Science" by SGT University, 21st- 25th Feb 2022.

EXTRA CURRICULAR ACTIVITIES

·2023: Life Member of Society for Materials Chemistry (SMC), BARC, Mumbai, Membership No. LM 1801.
·2023: Organizing Committee Member of AGORA-23, 2nd International Conference, Organized by Division of Forensic Science, SBAS, Galgotias University, Greater Noida, U.P
2022: Honorary Member of Global Academy of Forensic and Investigative Medicine and Sciences, Membership ID is: GA91-22079
2021: Organizing Committee Member of AGORA-21, 1st International Conference, Organized by Division of Forensic Science, SBAS, Galgotias University, Greater Noida, U.P.
2021: Organizing Committee Member of Five-day Faculty Development Program on 'Interdisciplinary research in Forensic Science' Organized by Department of Forensic Science, SBAS, Galgotias University, Greater Noida, U.P
·2021: Organizing Committee Member of Two days National Workshop on Cyber Crime Investigation-CDIT 2021 Organized by Department of Forensic Science, SBAS, Galgotias University, Greater Noida, U.P on January 23-24,2021.
2020: 1st Position in Poster Presentation – All India Forensic Science Meet on "National Forensic Colloquium for the Sustainable Development of Forensic Science", Forensic Science Unit, SGTB Khalsa College, University of Delhi- Delhi- 110007.
2019: Organizing Committee Member of AGORA-19, 4th National Conference, Organized by Department of Forensic Science, SBAS, Galgotias University, Greater Noida, U.P.
• 2018: Life Member of Indian Criminology & Forensic Science Association (ICFSA), registration number ICFSA-LM/2018/F122.

CONTACT DETAILS

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WORKSHOPS, CONFERENCES & SEMINARS

•2021: Workshop on 'IPR ' by Galgotias University on 23rd-27th October 2021.
2021: 2 Week Faculty Development Program on 'Developing online Courses for swayam, 14th- 28th Sept 2021.
. 2021: Conference on 'International Forensic Forum 2021: Traversing through the crime, criminal mind to the courtroom by Sharda University, 28th-30th June 2021.
2021: Workshop on 'General Practices of Publishing" by Galgotias University on 3 Feb 2021.
•2020: Five-day Faculty Development Program "Multidimensionality in Forensic Science Education" organized by Amity University Haryana,26-30 Dec 2020
•2020: 5 Days TEQIP III sponsored by Faculty Development Program on "Mathematical Computational Modelling", organized by Rajasthan Technical University,8dec-22 Dec 2020
2020: Certificate of Participation in virtual Workshop on Research writing skills, from 26- 30th May 2020, Hosted by UCRD, Galgotias University, UP.
• 2020: Certificate of Participation in the virtual conference on Food Forensics: Investigating food crimes and Frauds on 17th and 23rd May 2020, Hosted by GFSU, Gujarat.
• 2020: Certificate of Participation in 2 days virtual conference on Prevalent crisis triggered by the covid 19 pandemic and its appraisal, Organised by the Department of Chemistry & Biomedical Sciences of BCAS, on 18-19th May 2020, hosted by the University of Delhi.
2020: All India Forensic Science Meet (AIFSM-2020, National Conference) on "National Colloquium for the Sustainable Development of Forensic Science", SGTB Khalsa College, University of Delhi, Delhi.
• 2020: Certificate of Completion: Supporting Every Student Online: Differentiating Literacy Instruction Across Content Areas, on 21st April 2020, Presented by Shaelynn Farnsworth, Coach, Consultant, and Educator, and Steven W. Anderson, Digital Learning and Relationship Evangelist, Web20 Classroom, Organized by Edweb.
• 2020: Certificate of Excellence on completion of each module within Ethics Course, on 20th April 2020, by Research Academy Elsevier.
• 2020: Certificate of Excellence on completion of each module within the Writing Skill Course, on 20th April 2020, by Research Academy Elsevier.
• 2020: Certificate of Excellence on completion of each module within Research Data Management, on 20th April 2020, by Research Academy Elsevier.
• 2020: Certificate of Participation in Virtual International Conference on Role of Forensics in Criminal Investigation on 20 April 2020 Organized by the Department of Forensic Science and Criminal Investigation, Legal Desire Media & Insights.
• 2019: 4th National conference AGORA-19 on "Forensic Science and Cyber Threats: Countermeasures", Department of Forensic Science, Galgotias University, Uttar Pradesh.
• 2019: 1st Hands-on Workshop on "Human Remains and Recovery: Exhumation to Examination", Department of Forensic Medicine, All India Institute of Medical Sciences, Jodhpur, Rajasthan