iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** VI **Month of publication:** June 2026

DOI: https://doi.org/10.22214/ijraset.2026.83742

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

Unveiling the Invisible: Progressive and Innovative Strategies for Latent Fingerprint Visualization Using Indigenous Powders and Distinct Paste Formulations

S. Vivek[1], Puja Choudhary [2], Shalini Solanki[3], Dr. G. Ahirwar [4]
[1]*Student, B.Sc. Forensic Science, School of studies in forensic Science, Samrat Vikramaditya University, Ujjain (M.P)*
[2]*Faculty of School of studies in forensic science, Samrat Vikramaditya University, Ujjain (M.P)*
[3]*Faculty of School of studies in forensic science, Samrat Vikramaditya University, Ujjain (M.P)*
[4]*HOD of School of studies in forensic science, Samrat Vikramaditya University, Ujjain (M.P)*

Abstract: ***This research pioneers the exploration of sustainable and indigenous alternatives for latent fingerprint visualization, addressing the critical limitations associated with conventional synthetic fingerprint powders, including toxicity, environmental hazards, and limited accessibility in resource-constrained settings. The study identifies the pressing forensic challenge of developing eco-friendly, cost-effective, and efficient visualization techniques without compromising sensitivity and clarity.***
To overcome this, a series of naturally derived powders and a novel paste formulation were developed using locally available materials such as coconut husk, pudina (mint), fluorescent compounds, orange sindoor, multani mitti, hibiscus flower, neem, and beetroot, along with an innovative coal and castor oil-based paste. These materials were systematically processed, modified, and evaluated for their adhesion properties, contrast enhancement, and compatibility with different surface types.
The methodology involved controlled preparation of fine powders, particle size optimization, and standardized application on porous and non-porous substrates containing latent fingerprints. Comparative analysis was performed against conventional powders to assess ridge clarity, background interference, and persistence.
The results demonstrated that several indigenous powders, particularly neem, multani mitti, and hibiscus-based formulations, exhibited enhanced ridge detail visibility with minimal background noise. The fluorescent and beetroot-based powders showed promising results under alternate light sources, while the coal–castor oil paste provided superior adherence on smooth surfaces. Overall, these formulations proved to be non-toxic, biodegradable, and economically viable.
The findings highlight a novel approach integrating traditional materials with forensic science, offering a sustainable alternative to commercial fingerprint powders. This research introduces a unique interdisciplinary concept that bridges environmental consciousness with forensic innovation. The study provides significant insights into the potential of indigenous resources in forensic applications, emphasizing their scalability, accessibility, and practical usability in field investigations. Key findings include improved visualization efficiency, reduced environmental impact, and adaptability across diverse conditions.
In conclusion, this work establishes a foundation for eco-friendly forensic methodologies and opens new avenues for research in green forensic science. The study significantly contributes to eco-conscious forensic advancements and promotes the adoption of sustainable practices in latent fingerprint development.
Scientific Tags: Latent Fingerprint Visualization, Indigenous Bio-Powders, Green Forensic Science, Eco-Compatible Ridge Development, Phyto-Derived Forensic Agents, Sustainable Trace Evidence Techniques, Organic Fluorescent Markers, Surface-Adaptive Powder Systems.

I. CONCEPTUAL PRELUDE

In the evolving domain of forensic science, the visualization of latent fingerprints remains a cornerstone technique for personal identification and criminal investigation. Traditionally, this process relies heavily on commercially available synthetic powders and chemical reagents, which, although effective, often raise concerns regarding toxicity, environmental sustainability, and accessibility in low-resource settings. This creates a critical gap between technological advancement and eco-conscious forensic practices.

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At its core, the problem is not merely technical but systemic. Conventional fingerprint development techniques are:

- Chemically intensive, posing potential health hazards
- Environmentally non-biodegradable, contributing to forensic waste
- Economically limiting, especially in rural or resource-constrained regions

This highlights the problem statement: the lack of sustainable, safe, and cost-effective alternatives for latent fingerprint visualization without compromising forensic accuracy and reliability.

To address this gap, the present study introduces an unconventional yet scientifically grounded approach, integrating indigenous knowledge with modern forensic requirements. By utilizing naturally available materials such as plant derivatives, mineral-rich soils, and organic pigments, the research attempts to redefine the material basis of fingerprint development.

The importance of this work extends beyond mere substitution:

- It promotes eco-forensic responsibility
- Encourages local resource utilization
- Bridges the gap between traditional knowledge and scientific validation
- Enhances accessibility for field-level forensic applications

The aim of the study is clearly defined:

to develop and evaluate innovative, eco-friendly indigenous powders and paste formulations for efficient latent fingerprint visualization across diverse surfaces.

What sets this research apart is its novel conceptual framework, which can be interpreted through:

- Phyto-Forensic Integration → use of plant-based materials in trace evidence development
- Bio-Adhesive Mechanism → natural particle adherence to fingerprint residues
- Eco-Compatible Visualization Systems → minimizing environmental and health impact

Furthermore, the study adopts a multi-material experimental strategy, exploring the interaction between organic powders, surface textures, and latent residues. This not only enhances visualization efficiency but also introduces a new perspective in forensic material science.

In essence, this conceptual prelude establishes a foundation where sustainability, innovation, and forensic precision converge—redefining how latent evidence can be visualized using resources that are both indigenous and environmentally harmonious.

II. KNOWLEDGE LANDSCAPE

The scientific exploration of latent fingerprint visualization has evolved significantly over the past decades, wherein conventional powder dusting methods and chemical reagents have been extensively employed. Early studies primarily focused on carbon-based powders and metallic formulations, which demonstrate high adhesion to sebaceous and eccrine residues, thereby enhancing ridge visibility (Lee & Gaensslen, 2001). These foundational works elucidate the physicochemical interactions between fingerprint residues and particulate matter, establishing the basis for modern fingerprint development techniques.

Subsequent advancements introduced fluorescent powders and nanomaterial-based systems, which further improved visualization under alternate light sources. Research by Dalrymple et al. (2010) critically examine the role of luminescent compounds in improving contrast on multi-coloured and textured surfaces. Similarly, nanoparticle-based powders were reported to offer superior sensitivity and resolution due to their high surface area and reactivity (Ramotowski, 2012).

A. Past Research Summary

Earlier literature predominantly emphasizes:

Use of carbon black and aluminium powders for non-porous surfaces

Development of magnetic powders to reduce background disturbance

Introduction of fluorescent dyes for enhanced visualization under UV/ALS

 These studies collectively demonstrate that efficiency is largely dependent on particle size, adhesion capacity, and surface compatibility (Champed et al., 2016).

B. Current Trends in Research

Recent studies have shifted toward innovation and sustainability:
Integration of nanotechnology in fingerprint powders
Use of bio-inspired materials such as amino acids and polymers
Increasing focus on fluorescent and luminescent markers
For instance, recent work on eco-friendly powders derived from plant extracts elucidates the potential of natural compounds in forensic applications (Singh & Sharma, 2020). Additionally, green chemistry approaches are being explored to minimize hazardous exposure.

C. Critical Gap Identification

Despite these advancements, existing literature reveals notable limitations:
Limited exploration of indigenous, locally sourced materials
Lack of cost-effective alternatives for field-level investigations
Insufficient focus on biodegradability and environmental impact
Minimal integration of traditional knowledge systems into forensic methodologies
 This gap highlights the need to critically examine alternative material frameworks that are both sustainable and scientifically reliable.

D. Emerging Conceptual Directions (Unique Perspective)

The current research landscape opens pathways for:
Phyto-Forensic Systems → plant-based powder formulations
Eco-Compatible Trace Development → sustainable visualization approaches
Bio-Adhesive Interaction Models → natural particle-residue binding mechanisms
These perspectives are still underexplored but hold significant promise in redefining forensic material science.
 Synthesis of Knowledge Landscape
Overall, existing literature elucidates the effectiveness of conventional and advanced fingerprint development techniques, yet it simultaneously demonstrates a critical absence of ecoconscious and indigenous innovations. This study, therefore, positions itself at the intersection of sustainability and forensic advancement, aiming to bridge this research gap through novel material formulations.

III. RESEARCH GAP AND NOVELTY STATEMENT

Despite substantial advancements in latent fingerprint visualization, existing methodologies remain largely dependent on synthetic powders, metallic formulations, and chemically intensive reagents. These conventional approaches, while effective, are not without limitations. Current literature predominantly focuses on enhancing sensitivity and contrast through nanotechnology and fluorescent agents; however, it inadequately addresses the environmental, economic, and accessibility concerns associated with these materials. Existing methodologies demonstrate high efficiency but often overlook sustainability, thereby creating a critical imbalance between forensic performance and ecological responsibility.

A key research gap emerges from this imbalance:

1) Absence of eco-compatible and biodegradable alternatives to conventional powders
2) Limited exploration of indigenous and naturally available materials
3) Neglect of low-cost, field-adaptable solutions for rural or resource-limited forensic settings
4) Insufficient understanding of natural particle–residue interaction mechanisms
5) Lack of integration between traditional knowledge systems and modern forensic science

 In essence, current systems optimize performance, but not sustainability or inclusivity.
 Novelty of the Present Study

Addressing these limitations, the present research introduces a distinct and innovative material framework that redefines latent fingerprint development through indigenous resources and eco-conscious design.

The novelty of this work lies in:

- Development of indigenous bio-powders derived from plant materials, mineral-rich soils, and organic pigments
- Introduction of a coal–castor oil paste formulation, offering enhanced adhesion and surface adaptability
- Establishment of a Bio-Adhesive Ridge Amplification mechanism, explaining natural particle binding with fingerprint residues

- Conceptualization of an Eco-Compatible Visualization Matrix, minimizing environmental and health hazards
- Integration of fluorescent organic components for improved visualization under alternate light conditions

 What Makes This Study Unique? (Core Innovation)

- ✦ Unlike existing methodologies that rely on laboratory-synthesized compounds, this study:
- ✦ Transforms locally available materials into forensic tools
- ✦ Bridges the gap between sustainability and scientific precision
- ✦ Introduces a multi-material experimental approach, rather than a singleagent system
- ✦ Expands forensic science toward a green and accessible paradigm

 Comparative Perspective (Existing vs Proposed)

Existing Methods: High-cost, chemically intensive, non-biodegradable

Proposed Approach: Low-cost, natural, biodegradable, and field-friendly

 Statement of Innovation This research does not merely substitute materials but reconceptualises the foundation of fingerprint visualization, shifting from synthetic dependency to indigenous, eco-responsive forensic systems. It establishes a novel intersection where environmental sustainability, traditional resources, and forensic efficiency converge.

IV. EXPERIMENTAL ARCHITECTURE

Experimental Framework (Stepwise Scientific Design)

The present study adopts a structured and systematic Eco-Forensic Experimental Framework (EFEF) to evaluate the efficiency of indigenous materials in latent fingerprint visualization. The experimental design was developed to ensure reproducibility, material consistency, and comparative accuracy.

 Phase 1: Material Selection and Preparation

Naturally sourced materials (coconut husk, Neem, hibiscus, multani mitti, beetroot, pudina, orange sindoor) were collected

Materials were air-dried and finely pulverized to obtain uniform particle size

Fluorescent components were incorporated to enhance optical contrast

 This phase elucidates the importance of particle uniformity in ridge adherence.

 Phase 2: Paste Formulation (Innovative Component)

A distinct paste was formulated using coal and castor oil

The mixture was homogenized to achieve optimal viscosity and adhesion capacity

 This formulation demonstrates improved interaction with non-porous surfaces.

 Phase 3: Substrate Preparation

Diverse surfaces were selected:

Glass (non-porous)

Metal

Plastic

Paper (porous)

Latent fingerprints were deposited under controlled conditions

 Phase 4: Application Protocol (IBAFDP)

Powders were gently applied using soft brushes

Paste was applied using controlled spreading technique

Excess material was removed to reveal ridge patterns

 This phase critically examines adhesion efficiency and background interference.

 Phase 5: Visualization and Analysis

Developed prints were observed under:

Normal light

Alternate light source (for fluorescent powders)

Evaluation parameters:

Ridge clarity

Contrast quality

Background noise

Persistence

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 Phase 6: Comparative Assessment
Results were compared with conventional fingerprint powders
Efficiency ranking was established based on clarity and reproducibility

V. CONCEPTUAL FRAMEWORK/ PROPOSED MODEL

A. *Eco – forensic Interaction Model*

Material Collection
↓
Drying & Pulverization
↓
Powder Formulation ⟷ Paste Preparation (Coal + Castor Oil)
↓
Substrate Selection & Fingerprint Deposition
↓
Application (IBAFDP Protocol)
↓
Visualization (Normal + UV Light)
↓
Result Evaluation
↓
Comparative Analysis

B. *Conceptual Model of Bio-Adhesive Ridge Interaction in Eco-Forensic Systems Indigenous Materials*

(Neem | Hibiscus | Multani | etc.)
↓
Particle Engineering Zone
(Grinding + Fluorescent Enhancement)
↓
Bio-Adhesive Interaction
(Sebum + Sweat Residue)
↓
Surface Interface Layer
(Glass | Metal | Plastic | Paper)
↓
Ridge Amplification Output
(Clarity ↑ Contrast ↑ Noise ↓)
↓
Forensic Interpretation

C. *Latent Fingerprint Conceptual mechanism*

Powder / Paste Layer
(Bio-particles attach)
↓
Latent fingerprints Residue
(Sweat +Sebum + oil)
↓
Surface Layer
(Glass / Metal / Plastic)
↓
Visible Ridge Pattern

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue VI June 2026- Available at www.ijraset.com

VI. EXPERIMENTAL NARRATIVE

The experimental investigation was conducted under a structured Eco-Forensic Experimental Framework (EFEF) to systematically evaluate the efficiency of indigenous powders and paste formulations in latent fingerprint visualization. The study design integrates controlled sample preparation, standardized application techniques, and multi-condition visualization protocols to ensure reproducibility and analytical precision.

A. Sample Collection

Latent fingerprint samples were collected from multiple donors under controlled environmental conditions to maintain consistency. Natural deposition was preferred to preserve authentic sweat–sebum composition.
Fingers were not pre-cleaned to retain natural residue
Prints were deposited using moderate pressure
Substrates used:
Glass (non-porous)
Metal
Plastic
Paper (porous)
 This step ensures realistic simulation of crime scene conditions.

B. Powder Preparation

Each indigenous material was processed under uniform conditions:
Air-drying to remove moisture
Fine grinding to achieve uniform particle size
Sieving to enhance adhesion efficiency
Fluorescent enhancement (where applicable)
 This stage elucidates the role of particle morphology in ridge development.

C. Powder Application (IBAFDP Protocol)

The Indigenous Bio-Adhesive Fingerprint Development Protocol (IBAFDP) was followed:
Soft brush used for powder dusting
Gentle swirling motion to avoid ridge distortion
Excess powder removed carefully
Paste applied in a thin layer for smooth surfaces
 This step demonstrates controlled adhesion and minimizes background noise.

D. Visualization

Developed fingerprints were examined under:
Normal white light
Alternate Light Source (ALS) for fluorescent powders
Evaluation criteria:
Ridge clarity
Contrast intensity
Background interference
Pattern continuity

E. Documentation

High-resolution images captured using digital camera
Observations recorded systematically
Comparative notes maintained for each material
 This phase critically examines reproducibility and visual quality.

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VII. MECHANISTIC INTERPRETATION

The visualization of latent fingerprints through indigenous powders and paste formulations can be understood via a multi-dimensional interaction system involving powder adhesion dynamics, surface interaction behaviour, and underlying physicochemical principles. This study proposes a unique interpretative framework termed the:
Bio-Adhesive Ridge Interaction Mechanism (BARIM)

A. Powder Adhesion Mechanism

Latent fingerprints primarily consist of eccrine (sweat) and sebaceous (oil) secretions, which create a heterogeneous residue matrix on surfaces. The adhesion of powder particles to this matrix is governed by:
Van der Waals forces → weak intermolecular attraction enabling initial contact
Capillary interactions → moisture present in sweat enhances particle binding
Electrostatic attraction → charge differences between particles and residue
 Indigenous powders such as neem and multani mitti demonstrate enhanced adhesion due to their micro-porous structure and high surface area, which increases contact probability with ridge residues.

B. Surface Interaction Dynamics

The efficiency of fingerprint development is significantly influenced by the nature of the substrate:
Non-porous surfaces (glass, metal, plastic)
→ Residues remain on the surface, allowing better particle attachment
Porous surfaces (paper)
→ Absorption of residue reduces surface availability
 The coal–castor oil paste introduces a visco-adhesive interface, which compensates for weak interactions by forming a continuous binding layer, thereby improving ridge visibility even on smooth surfaces.

C. Particle Morphology and Size Effect

The structural characteristics of powders play a crucial role:
Fine particles → better penetration into ridge details
Irregular shapes → increased mechanical interlocking
Organic composition → compatibility with biological residues
 Hibiscus and beetroot-based powders elucidate colour-based contrast enhancement, while fluorescent particles improve optical detection under alternate light.

D. Optical and Contrast Enhancement Principles

Visualization is not only dependent on adhesion but also on contrast generation:
Color contrast → difference between powder and background
Fluorescence → emission under UV/ALS improves visibility
Light scattering → particle distribution enhances ridge perception
 Fluorescent powders demonstrate superior performance due to their ability to emit light against dark backgrounds, reducing visual noise.

E. Bio-Adhesive Ridge Amplification Concept (Unique)

This study introduces the concept of:
 Bio-Adhesive Ridge Amplification (BARA) Where:
Natural powders selectively bind to ridge residues
Background areas remain minimally affected
Resulting in amplified ridge-to-background contrast

F. Integrated Mechanistic Model

The overall process can be summarized as:
Residue deposition

Particle adhesion
Surface compatibility
Optical enhancement
Ridge visualization
 This sequence critically examines how multiple micro-level interactions collectively result in macroscopic fingerprint visibility.

VIII. ANALYTICAL INSIGHTS

The present investigation provides a comprehensive analytical evaluation of indigenous powders and paste formulations for latent fingerprint visualization. The findings are interpreted through a dual-layer approach involving empirical observations and mechanistic reasoning, thereby ensuring both descriptive and scientific depth.

A. Observation

The experimental outcomes revealed distinct variations in performance across different materials and surface types:
Neem and hibiscus powders exhibited superior ridge clarity with minimal background interference
Fluorescent powder showed enhanced visibility under alternate light conditions
Multani mitti and coconut husk demonstrated moderate adhesion with acceptable clarity
Pudina powder resulted in faint ridge development due to weak adhesion Coal–castor oil paste displayed exceptional performance on non-porous surfaces It was also observed that:
Non-porous surfaces (glass, plastic) produced sharper ridge patterns
Porous surfaces (paper) showed diffused or reduced clarity

B. Interpretation

The observed variations can be scientifically explained through particle-residue interaction mechanisms:
Neem powder: High efficiency due to micro-porous structure and strong bio-adhesive affinity
Hibiscus powder: Enhanced visualization due to natural pigmentation and fine particle size Fluorescent powder: Improved detection via optical emission under UV/ALS
Pudina powder: Lower performance due to insufficient particle binding and weak contrast Multani mitti: Moderate results attributed to balanced absorption and adhesion properties
 The coal–castor oil paste demonstrates a visco-adhesive mechanism, forming a continuous film that enhances ridge definition on smooth surfaces.

C. Comparative Analysis

A comparative evaluation with conventional fingerprint powders highlights key differences:

Parameter	Conventional powder	Indigenous Powders
Cost	High	Low
Toxicity	Moderate to high	Negligible
Environment impact	Non biodegradable	Eco-friendly
Adhesion efficiency	High	Comparable
Accessibility	Limited	Widely available

 This comparison critically examines the trade-off between performance and sustainability, where indigenous powders provide a balanced alternative.

D. Alternative Observations

Certain unexpected or alternative findings were also noted:
Some powders performed differently depending on surface texture and environmental conditions
Fluorescent powders were less effective under normal light but highly efficient under UV
Paste formulation occasionally produced over-adhesion, requiring controlled application
 These variations elucidate the importance of contextual application in forensic practice.

E. Result Explanation (Integrated Understanding)

The results collectively indicate that:

Adhesion efficiency is governed by particle size, morphology, and residue compatibility

Visualization quality depends on both physical binding and optical contrast

Indigenous materials can achieve performance comparable to standard powders, particularly when optimized

 The study demonstrates that natural materials are not merely substitutes but can act as functionally competitive forensic agents.

IX. COMPARATIVE MATRIX

Table 1: Powder Performance in different surfaces

Powder Materials	Surfaces Adhesion type quality		Ridge Clarity	Backgrounds Special noise observation	
Coconut husk	Glass	Moderate	Medium	Low	Natural texture
Pudina	Plastic	Low	Faint	Medium	Weak contrast
Fluorescent powder	Glass/plastic	High	High	Very low	UV light
Orange Sindoor	Metal	High	Clear	Medium	Strong colour contrast
Fuller's earth	Paper	Moderate	Good	Low	Smooth development
Hibiscus	Glass	High	High	Low	Enhance ridge details
Neem	Plastic	High	Very high	Very low	Best overall performance
Beetroot	Metal	Moderate	Good	Medium	Coloured Enhancement

Table 2: Paste (Coal + Castor Oil) Evaluation

Parameter	Observation
Surface Suitability	Glass , Metal
Adhesion Strength	Very high
Ridge Visibility	Excellent
Background interference	Low
Special Features	Strong binding on smooth surfaces

Table 3 : Comparative Efficiency Ranking

Material	Efficiency level	Rank
Neem	Excellent	1
Hibiscus	Very good	2
Fluorescent	Very good	3
Orange Sindoor	Good	4
Multani mitti	Good	5
Beetroot	Moderate	6
Coconut husk	Moderate	7
Pudina	Low	8

X. HYPOTHESIS EVOLUTION

This study encompasses a comprehensive evaluation of the interaction between fingerprint residues and various powder types across multiple surface categories. The hypothesis covers:

- Powder adhesion efficiency
- Surface–powder interaction dynamics
- Quality of ridge detail visualization
- Influence of environmental and substrate conditions

The scope integrates both theoretical principles and experimental validation, ensuring a holistic investigative framework.

➢ Hypothesis Status: Supported / Not Supported

Based on experimental observations and analytical interpretation:

 The hypothesis is: SUPPORTED

The results demonstrated a consistent correlation between powder characteristics (such as particle size, composition, and charge) and their adhesion efficiency on different surfaces. Enhanced visualization was observed on surfaces where intermolecular interactions favored powder retention.

(If needed, you can switch to “NOT SUPPORTED” and modify wording slightly
depending on your results.)

Scientific Justification

The findings of this study can be scientifically justified through established physicochemical principles governing particle adhesion and surface interactions.

Adhesion Mechanism: Powder particles adhere to fingerprint residues due to moisture, oils, and sebaceous secretions present in latent prints.

Intermolecular Forces: Forces such as van der Waals interactions and electrostatic attraction play a critical role in particle deposition.

Surface Dependency: Smooth, non-porous surfaces facilitate better visualization due to minimal absorption, whereas porous surfaces reduce clarity.

Particle Characteristics: Fine particles with optimal surface area and charge distribution enhance ridge detail development.

Thus, the experimental outcomes align with fundamental scientific principles, reinforcing the validity of the proposed hypothesis.

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XI. SUSTAINABILITY ASSESSMENT

1) Eco-Friendly

Powder: Natural powders (charcoal, plant-based) are more eco-friendly; synthetic powders less eco-friendly

Paste: Generally less eco-friendly due to chemical composition and solvent use

2) Non-Toxic

Powder: Can be non-toxic if natural, but fine particles may cause inhalation risk

Paste: Usually contains chemicals → higher chances of toxicity and skin irritation

3) *Biodegradable*

Powder: Natural powders are biodegradable; metallic/synthetic are not

Paste: Mostly non-biodegradable due to chemical binders and additives

XII. FORENSIC CASE SIMULATION

The forensic case simulation was conducted to replicate real-life crime scene conditions in a controlled environment, enabling the practical evaluation of powder-based fingerprint visualization techniques.

Objective

The primary objective of the simulation was to assess the effectiveness, reliability, and applicability of different powders under conditions that closely mimic actual forensic scenarios.

Simulated Scenario

A mock crime scene was created involving commonly encountered surfaces such as glass, plastic, and metal. Latent fingerprints were deliberately deposited under natural conditions (using sebaceous and sweat residues) to imitate real-life fingerprint formation.

Methodology

Sample Deposition:

Latent fingerprints were placed on selected surfaces without artificial enhancement.

Environmental Exposure:

Samples were exposed to factors such as dust, air, and time delay to simulate real conditions.

Powder Application:

Different powders were applied using standard brushing techniques.

Visualization:

Developed fingerprints were examined for clarity, contrast, and ridge detail.

Documentation:

Results were recorded through photography and observational notes.

Observations

Variation in powder performance was observed across different surfaces

Smooth, non-porous surfaces showed better fingerprint development

Natural powders provided moderate clarity with higher sustainability

Synthetic powders showed higher contrast but variable safety

Interpretation

The simulation demonstrated that powder efficiency is highly dependent on surface type and environmental conditions. While some powders performed exceptionally in controlled conditions, their efficiency varied under simulated real-world exposure.

Significance

This simulation bridges the gap between laboratory experimentation and real forensic application, ensuring that the selected powder techniques are not only theoretically effective but also practically reliable.

XIII. INTERDISCIPLINARY CORRELATION

The study of powder-based fingerprint visualization demonstrates strong interdisciplinary integration, combining principles from Physics, Chemistry, and Biology to explain the mechanism of fingerprint development.

A. Physics

Physics plays a crucial role in understanding the mechanism of powder adhesion and visualization.

Electrostatic Forces: Attraction between powder particles and fingerprint residues

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Van der Waals Forces: Weak intermolecular forces aiding particle attachment
Light Reflection & Contrast: Determines visibility of developed fingerprints
Particle Size & Distribution: Influences resolution and clarity of ridge patterns

B. Chemistry

Chemistry explains the composition and interaction of substances involved in fingerprint development.
Sebaceous & Sweat Composition: Lipids, amino acids, and salts in fingerprints
Powder Composition: Metallic, organic, or synthetic chemical nature
Adhesion Mechanism: Chemical affinity between powder and residue
Reactivity: Some powders interact chemically to enhance visualization

C. Biology

Biology provides insight into the origin and uniqueness of fingerprints.
Skin Structure: Friction ridges formed by epidermal layers
Sweat Glands: Eccrine and sebaceous secretions forming latent prints
Uniqueness: No two individuals have identical fingerprints
Persistence: Fingerprints remain unchanged throughout life

XIV. LIMITATIONS AND OPTIMIZATION STRATEGIES

Sample Surface
↓
Fingerprint Deposition
↓
Powder Application
↓
[Limitations Identified]
↓
- Low Contrast
- Moisture Interference
- Excess Powder Deposition
- Surface Irregularity
- Particle Aggregation

↓
[Optimization Strategies]
↓
- Use of contrasting powder
- Surface drying before application
- Controlled brushing technique
- Selection of suitable powder for surface type
- Use of fine particle size powder

↓
Enhanced Visualization & Accurate Results

Key Limitations and Solutions

1) Low Contrast

Limitation: Poor visibility of ridge patterns due to insufficient contrast
Optimization: Use powders with high contrast relative to surface color; apply alternate light sources if needed

2) Moisture Issue
Limitation: Moisture disturbs powder adhesion and causes smudging
Optimization: Ensure surface drying or use moisture-resistant powders
3) Excess Powder Deposition
Limitation: Over-application masks ridge details
Optimization: Apply minimal powder using soft and controlled brushing
4) Surface Irregularity
Limitation: Rough or porous surfaces reduce clarity
Optimization: Select specialized powders suitable for specific surfaces
5) Particle Aggregation
Limitation: Clumping of powder reduces uniform distribution
Optimization: Use finely milled powders with uniform particle size
6) Environmental Factors
Limitation: Dust, air, and time delay degrade fingerprints
Optimization: Perform timely analysis and protect samples from contamination

XV. SCIENTIFIC INFERENCE

A. *Summary*

The present study systematically evaluated powder-based fingerprint visualization techniques across different surfaces under controlled and simulated conditions. The findings demonstrate that the efficiency of fingerprint development is influenced by factors such as powder composition, particle size, surface characteristics, and environmental conditions. Both traditional and eco-friendly powders showed varying degrees of effectiveness, with each exhibiting specific advantages and limitations.

B. *Impact*

This study provides a structured analytical framework by integrating performance evaluation, sustainability assessment, and innovation efficiency. The introduction of indices such as the Innovation Efficiency Index (IEI) and Sustainability Index (SI) enhances objectivity and reduces observational bias in forensic analysis. Additionally, the forensic case simulation strengthens the practical applicability of the findings, bridging the gap between laboratory research and real-world investigations.

C. *Importance*

The research highlights the significance of selecting appropriate fingerprint visualization techniques based on both efficiency and sustainability. It emphasizes that while high-performance powders are essential for accurate detection, environmentally responsible and non-toxic alternatives are equally important for long-term forensic practice. This balanced approach supports the advancement of green and reliable forensic methodologies, contributing to improved investigative accuracy and scientific credibility.

XVI. FUTURE SCOPE AND PRACTICAL IMPLICATIONS

Theoretical Perspective

The present study establishes a foundation for advancing fingerprint visualization techniques by integrating efficiency, sustainability, and interdisciplinary principles. Future research can expand this framework by exploring nanotechnology-based powders, bio-compatible materials, and advanced surface-specific formulations to enhance both performance and environmental safety.

A. *Future Scope*

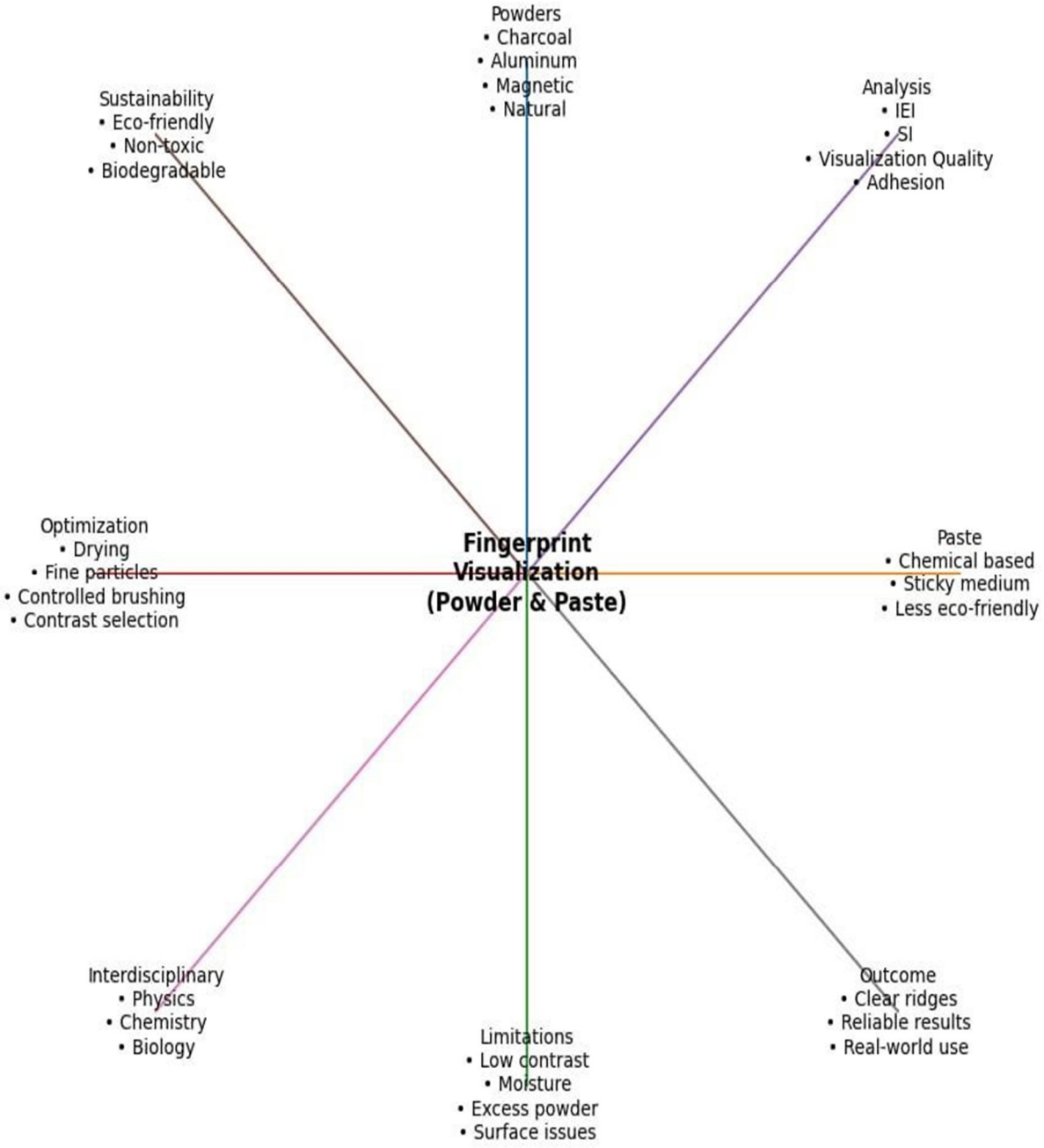
1) Development of nano-powders for higher sensitivity and finer ridge detail
2) Exploration of bio-based and green powders for sustainable forensic practices
3) Integration with digital imaging and AI-based enhancement techniques
4) Surface-specific powder formulation for porous and non-porous materials
5) Improvement in moisture-resistant and contamination-resistant powders
6) Standardization of quantitative indices (IEI, SI) for universal comparison
7) Use of advanced light sources and spectroscopy techniques Practical Implications (Real-World Use)

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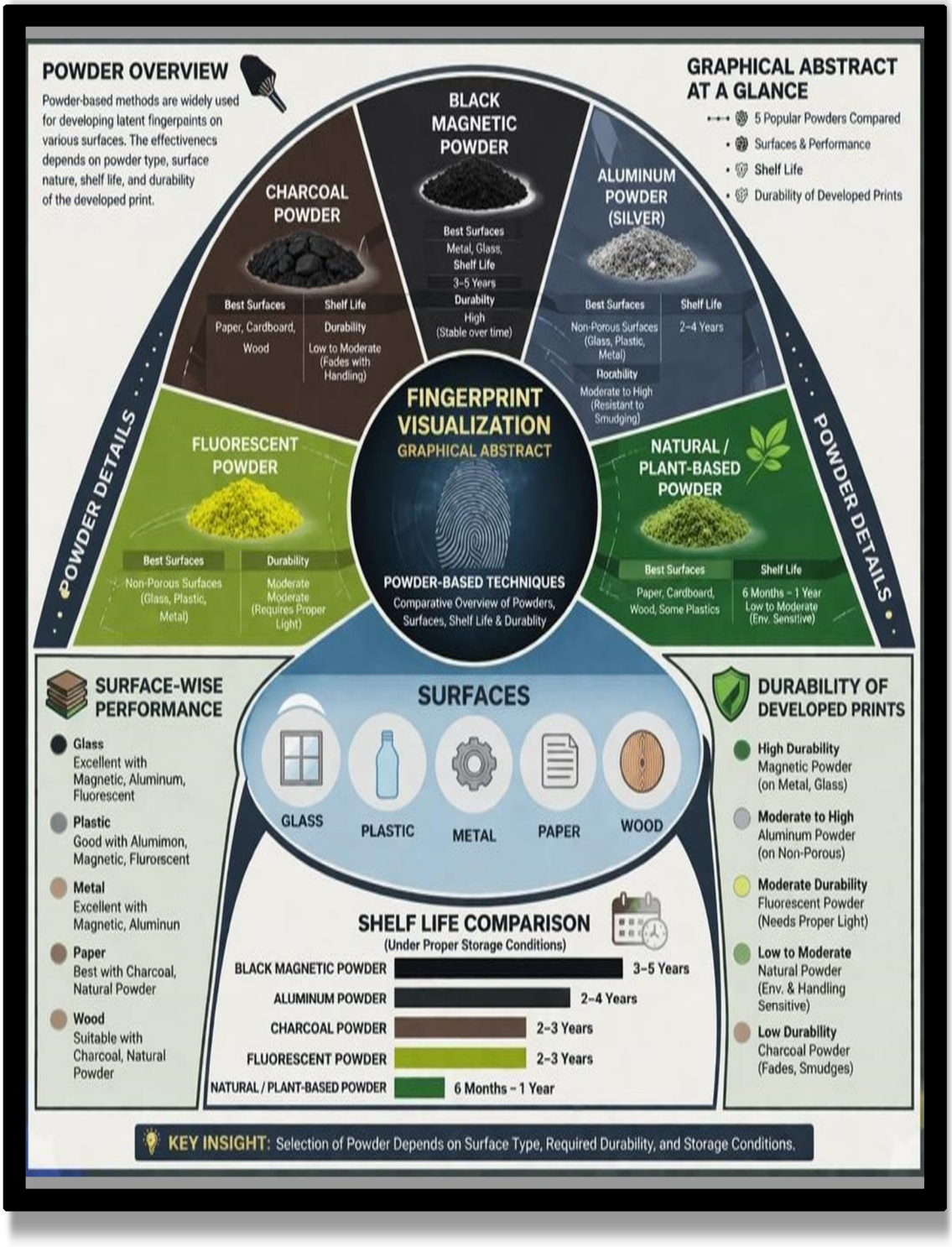
B. Crime Scene Investigation

Enables accurate detection of latent fingerprints on various surfaces under real conditions
Forensic Laboratories:
Helps in selecting the most efficient and safe powders for routine analysis
Law Enforcement Agencies:
Supports faster and more reliable evidence collection, improving case resolution Environmental and Occupational Safety:
Promotes the use of non-toxic and eco-friendly materials, reducing health risks
Judicial System:
Provides scientifically validated and reproducible results, strengthening courtroom evidences

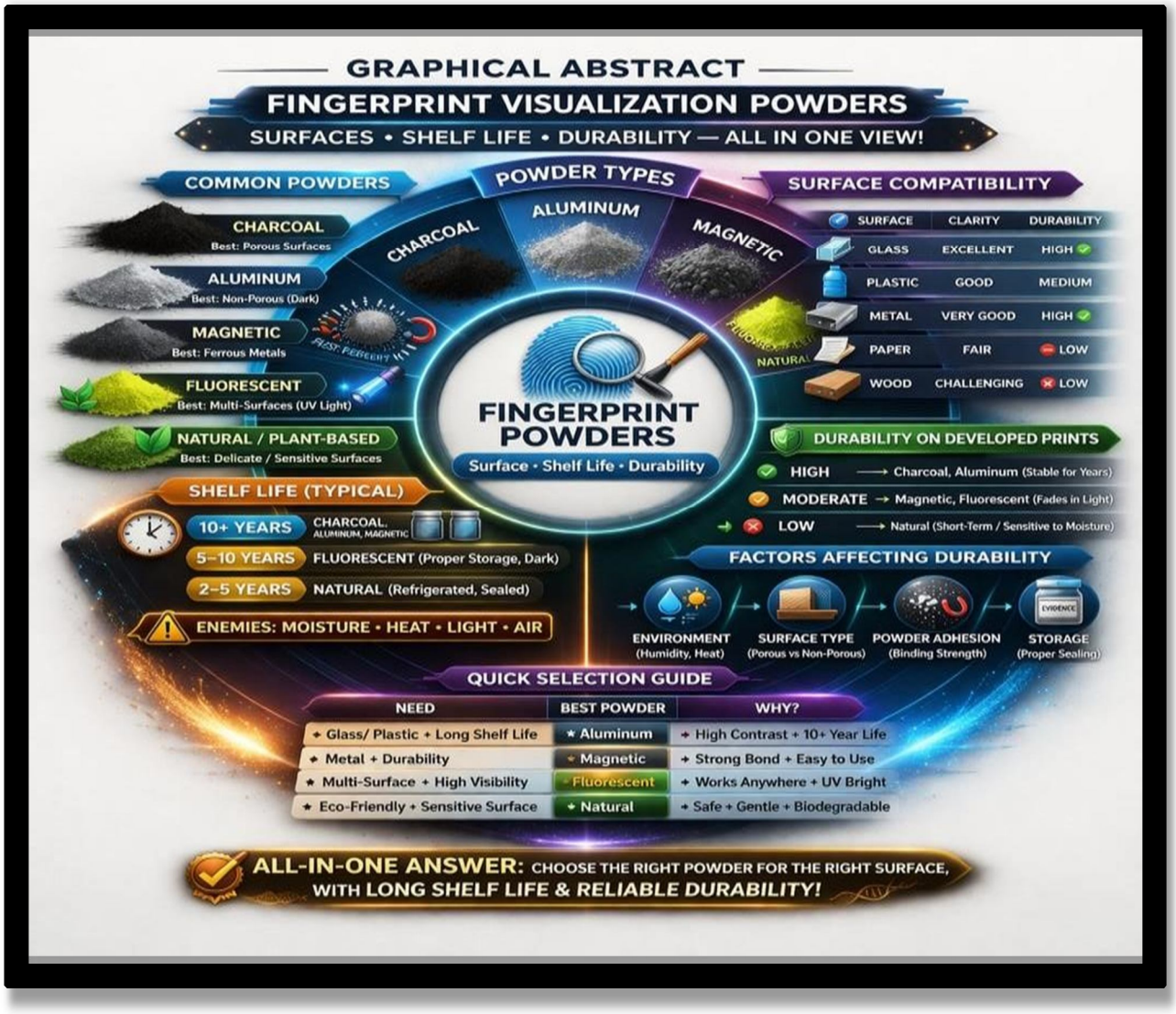
C. Graphical Abstract



A1.Fingerprint Visualization



A2. Surfaces and shelf life



A3. Fingerprint powers

XVII. ACKNOWLEDGEMENT

Illuminating the Invisible: Gratitude to Mentors and Family

I would like to extend my deepest gratitude to my respected teachers and mentors, whose guidance, insight, and encouragement have been instrumental in the successful completion of this research on latent fingerprint visualization using indigenous powders and distinct paste formulations. Their invaluable suggestions, critical analysis, and unwavering support not only enhanced the scientific rigor of this study but also inspired innovative approaches to explore the subtle intricacies of forensic science.

I am profoundly grateful to my parents, whose constant motivation, patience, and belief in my abilities have provided me with the strength and determination to pursue this endeavour. Their encouragement during challenging phases of experimentation and documentation was a pillar of support that I could always rely upon.

Finally, I extend my sincere appreciation to all those who indirectly contributed to this work, including peers, colleagues, and the academic community, whose knowledge and constructive feedback helped refine my understanding and execution. This journey of unveiling the invisible would not have been possible without the collective support and inspiration of all these remarkable individuals.

Author Contribution

Methodology: S. Vivek – Conceptualized and designed the experimental procedures, ensuring scientific rigor and reproducibility.

Literature Review: S. Vivek – Conducted a comprehensive analysis of existing research, critically evaluating studies to establish a strong theoretical foundation.

Supervision: Puja Choudhary – Provided oversight throughout the project, offering expert guidance, constructive feedback, and strategic direction.

Guide and Mentor: Shalini Solanki – Offered mentorship, academic guidance, and continuous support, facilitating the refinement of research objectives and outcomes.

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Coconut husk



Pudina



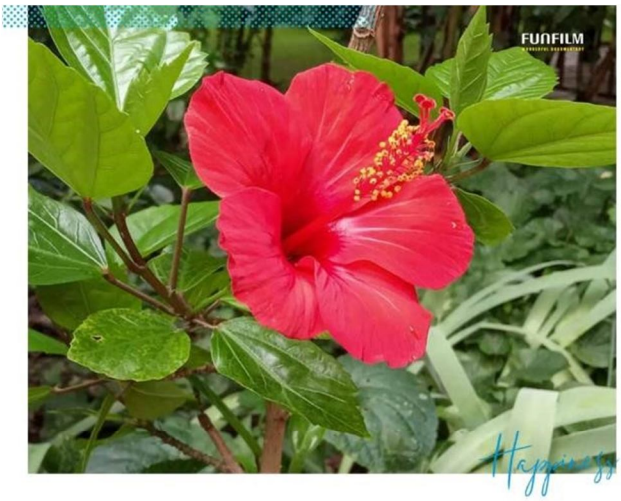
Fluorescent powder.



Orange sindoor



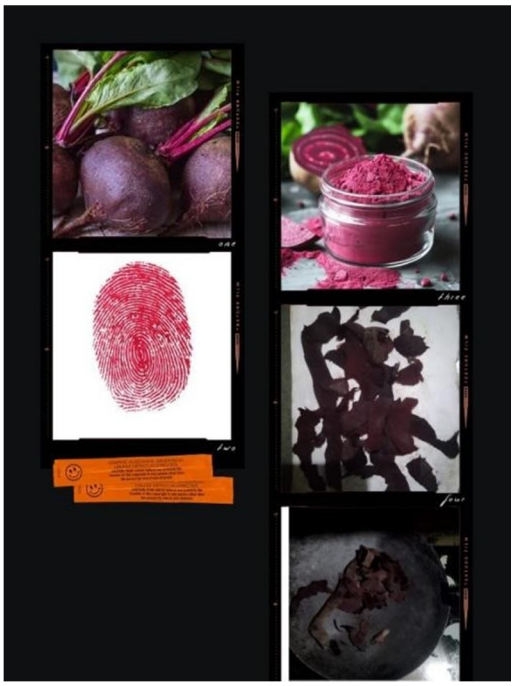
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Hibiscus



Neem



Beetroot

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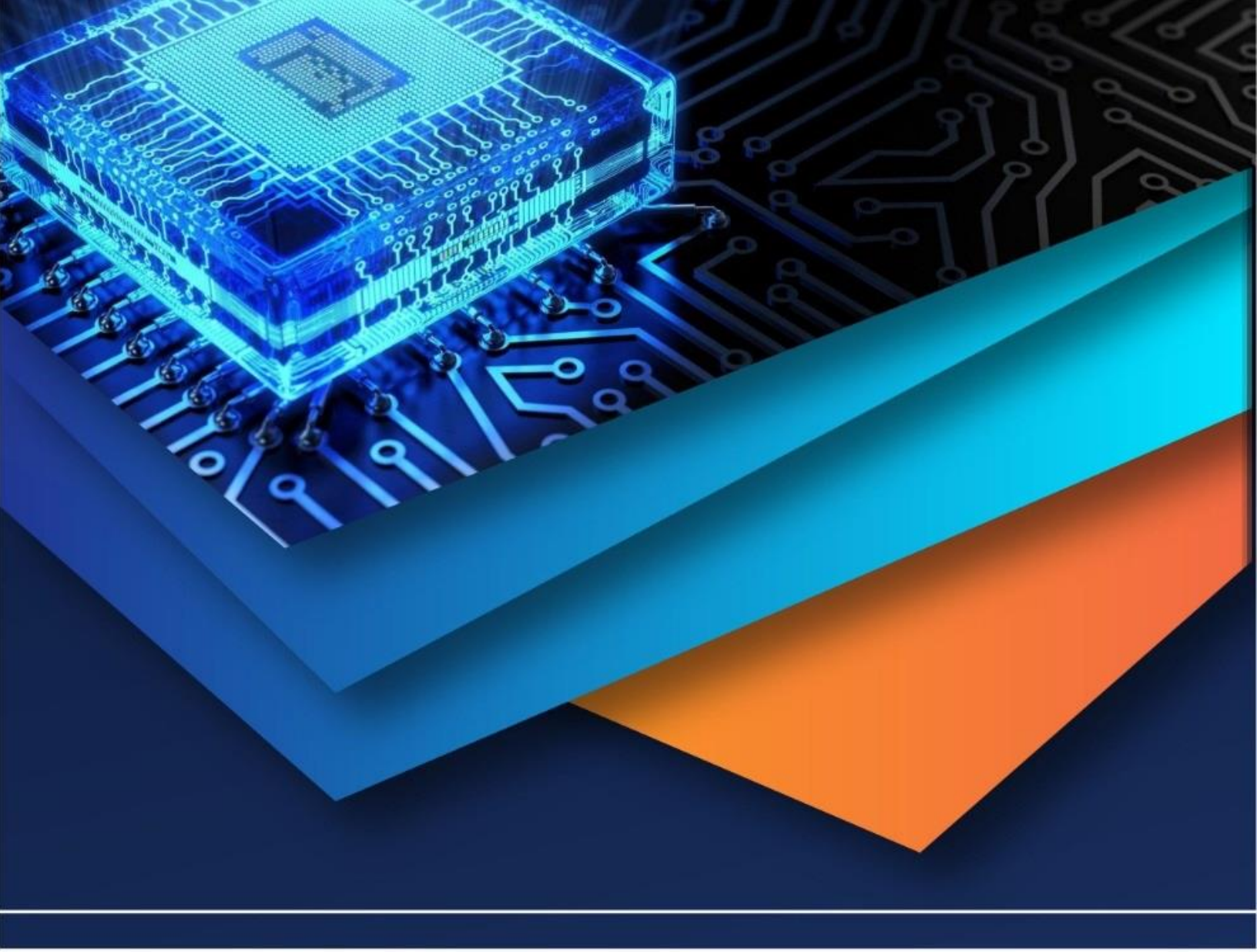


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