



Research Paper

Utilizing Activated Carbon from the Date Fronds to Detect Latent Fingerprints


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ABSTRACT

Background: In this work, a fingerprint powder was used to reveal latent fingerprints from different surfaces. This powder was derived from the Date fronds as activated carbon.

Methods: In preparing the activated carbon, three parameters were studied: activation time, activation temperature, and impregnation ratio. Fourier Transform Infrared Spectroscopy (FTIR) was used to characterize the prepared Date frond activated carbon (DFAC) as well as the raw material (Date frond plant). Brunauer-Emmett-Teller (BET) was used to measure the specific surface area of DFAC. The surface shape and the element composition of the prepared powder were investigated using (SEM-EDS) analysis. A Central Composite Design (CCD) was employed to determine the optimal preparation conditions and to elucidate the relationship between the studied parameters and the response (yield). Sodium acetate and mineral oil were added to the (DFAC) powder in five different concentrations to enhance the intensity of the expression, thereby revealing latent fingerprints.

Results: The results show that the best powder recipe was one with 20% sodium acetate and mineral oil, respectively. The Date frond activated carbon (DFAC) powder was compared with the commonly used importer powder (Sirchie) and tested for several surfaces. Additionally, the time of the latent fingerprints' presence on the surfaces was determined. It took fifteen days to notice the perfectly distinct fingerprint.

Conclusion: Activated carbon derived from Date fronds was successfully used to reveal latent fingerprints on various non-porous materials. The Date frond activated carbon (DFAC) powder showed good adherence to friction ridges and was more effective than the commercial Sirchie powder, DFAC demonstrated similar excellent results in displaying detailed fingerprint patterns. Enhancing the DFAC powder with sodium acetate and mineral oil improved the visualization intensity, with the optimal formula being 20% sodium acetate and 2% mineral oil.

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Introduction

When fingers contact an object or surface; their friction skin ridges leave an impression. The fingerprint is a major, robust human identification tool in forensic investigations, as it is remarkably unique to only one individual [1]. The fingerprints of both the perpetrator and the victim are the most typical but unseen evidence left behind at the crime scene. These fingerprints provide nearly perfect verification of a person's presence at the crime scene, as each individual has a distinct fingerprint pattern [2]. They are easily distinguishable from one another due to their distinct ridges and patterns. Fingermarks are composed of water, minerals, fatty acids, and amino acids. They can be defined as the impressions of specific areas left on the skin surface of a friction ridge using different analytical techniques [3]. Hidden fingerprint evidence has been discovered using a variety of chemical and physical methods on various surfaces [4]. However, each of the physical and chemical procedures has its advantages and disadvantages; therefore, it is up to the fingerprint expert's knowledge and experience to choose the most effective method for developing latent fingerprints [5].

To develop latent fingerprints from any solid surface, a general rule of thumb is to use a suitable fingerprint powder with specific surface-related properties. Commercial fingerprint powders, on the other hand, are frequently restricted to only specific surfaces and development conditions, limiting their application to other surfaces, crime scenes, or even the level of user expertise. Forensically, there are three different types of fingerprints: visible, plastic, and latent [6]. According to reports, latent fingerprints are the most prevalent type of fingerprints found at crime scenes [7]. Such prints typically require the use of enhancement techniques, such as powder dusting, due to their invisibility [8]. Because of its low cost, simplicity, and effectiveness, powder dusting has become a popular method for visualizing fingerprints [9]. The mechanical adhesion of powder and the overall composition of fingerprints are the primary determinants of the procedure's success [10]. Powders come in a variety of forms, including regular, metallic, and luminescent powders [11].

The regular powder consists of two main components that facilitate the powdering process. There is a colorant that provides color contrast to the background, and a resinous polymer that helps with adhesion [11]. Metallic powder is a powder formed from mesh metals. The luminous powder is composed of organic compounds that glow when exposed to light.

Various types of powders have their limitations. No powder can be applied to all types of surfaces. Some powders are only effective on specific surfaces [2]. Although some powders can be used on a variety of surfaces, there are still some limits. Some of the previously utilized fingerprints were unable to give a good color contrast with the surface of the background [12].

The traditional powder-dusting approach has several drawbacks, including toxicity, limited contrast, low sensitivity, and high interference from autofluorescence. Therefore, activated carbon has developed as a better option for overcoming these disadvantages and providing more precise and accurate results. In the same direction, various experts and scientists contributed to the invention of powders and their exploration for enhancing hidden fingermarks with improved character development [13].

Several powder-dusting options have recently been introduced to enhance the quality and contrast between the visualized fingerprints and the dry, non-porous object or surface. The two most common color types of powder dusting used in detecting latent fingerprints are white (titanium-based) and black (carbon-based). However, some of the chemicals utilized in the powders are toxic to users and can cause cancer. For instance, titanium dioxide, sometimes known as white powder, has been cleared by the International Agency for Research on Cancer (IARC) to be hazardous to people and may even cause cancer [15]. Additionally, using commercially available lead and mercury-based powders for an extended period may pose a risk to the user's health. Therefore, it is crucial to identify a less harmful alternative that is equally effective in identifying latent fingerprints on dry, non-porous surfaces [16]. Natural carbon components, such as charcoal and active carbon, have long been a mainstay of conventional fingerprint formulations (primarily in the form of grey and black powder) [17]. This study aims to investigate and develop an effective, environmentally friendly, and economically viable fingerprint powder derived from the activated carbon of Date fronds for the visualization of latent fingerprints on various non-porous surfaces. The study aims to optimize the preparation conditions of activated carbon from Date fronds by examining critical parameters, including activation time, activation temperature, and impregnation ratio, using a Central Composite Design (CCD) approach to maximize yield and efficacy.

Additionally, the study investigates the effects of adding sodium acetate and mineral oil to improve powder adherence and visualization intensity. Another key objective is to compare the performance of the

DFAC powder with that of conventional commercial fingerprint powders to assess its suitability as an alternative. The study also aims to evaluate the longevity of latent fingerprints developed using the DFAC powder under typical conditions, determining how long clear fingerprint visualization can be achieved.

Materials and Methods

Materials

The Alhagi plant was collected from areas where it is available in Baghdad. After chopping the plant into tiny pieces, the surface was thoroughly cleaned with distilled water to remove any dirt. Next, it was dried for 24 hours at 60°C and then crushed to the desired size of 2 mm. Potassium hydroxide (KOH), supplied by Himedia, India, was used as a chemical activation agent. Sodium acetate was provided by Fisher Chemical (AR). Mineral oil was purchased from Sigma-Aldrich (St. Louis, MO, United States). In the carbonization step, nitrogen was employed as an inert gas to stop the combustion of the raw materials. In this investigation, all chemical reagents used were of analytical grade.

Experimental procedure

Preparation of activated carbons

The dried date fronds pieces were impregnated with potassium hydroxide (KOH) solution at varying impregnation ratios (weight of dried mass to weight of KOH) and left overnight at room temperature. After separation from the base residue, the samples were thoroughly washed with distilled water and dried at 100°C for two hours.

The impregnated samples were then carbonized by heating them inside a stainless-steel box within a furnace under a purified nitrogen flow (120 cm³/min) to a predetermined temperature. Following carbonization, the samples were cooled to room temperature under the same nitrogen atmosphere. The resulting carbon powder was washed with hot distilled water until the wash water reached a pH of 6–7 to remove any residual base.

Finally, the carbonized material was dried at 60°C for 24 hours, ground into a fine powder, sieved to a particle size of 45 microns, and stored in a sealed container to prevent moisture uptake.

Additives

To enhance the performance of the prepared activated carbon in revealing latent fingerprints, the addition of sodium acetate and mineral oil in specified

quantities to the (DFAC) was investigated. Five grams of activated carbon were added to (5%, 10%, 15%, 20%, and 25%) by weight of sodium acetate (in an aqueous solution form), then dried at a temperature of 105 °C for 3 hr. Additionally, in some experiments, mineral oil was added to DFAC and sodium acetate together at ratios of 0.5%, 1%, 1.5%, 2%, and 2.5% (v/w). The recipe was again dried at a temperature of 70°C for 1 hour. The final powder was covered with plastic to prevent exposure to moisture.

Development and recording of latent fingerprints

The following standard procedure was used to collect fingerprints from all donors in this study. The donor began by washing his hands with soap and water. The fingers were then gently rubbed across the top of the head. On various substrates (surfaces), fingerprints were deposited with low pressure. These latent fingerprints were naturally mixed, as they contained both eccrine and sebaceous secretions. The relevant power should be applied within a circular motion by a fingerprint brush. It is important to avoid smudging the imprint. After that, clean the surface gently with light tapping to remove any remaining powder. It is necessary to photograph the developed print. Finally, the fingerprints were recorded and lifted with tape. All photos were taken with a digital camera in natural light with an Apple iPhone MAX.

Characterization of the active carbon

The functional groups found in the Date fronds and Date frond-activated carbon compositions were determined using FTIR (IR Affinity-1 Shimadzu, Japan). The topographical features and morphology of the surface were investigated with a scanning electron microscope (SEM). The surface shape is accurately represented in the three-dimensional images that are produced. An energy-dispersive X-ray spectrophotometer (EDS) was used to analyze the precursor elements. The electron microscope TESCAN Vega III from the Czech Republic was used to perform the SEM-EDS analysis. The specific surface area was calculated using the Brunauer-Emmett-Teller (BET) method (HORIBA, SA-900 series, USA).

Design of Experiments

Activated carbon (AC) production from date fronds and investigation of the optimal production conditions are among the research goals. Numerous variables, including activation temperature, activation duration, and impregnation ratio (IR, defined as the weight of char to the weight of KOH), affect the chemical activation process that produces Date frond-activated carbon (DFAC). Typically, the purpose of experimental design is to ascertain, with the least number of experiments possible, the relationship between the response and the

factors. Central Composite Design (CCD) was used to examine the effects of these factors. The activation temperature was selected to range between 500°C and 800 °C, while the impregnation ratio was set at 1:1 to 1:3, and the activation time was set between 1 and 4 hours. The response is the yield of activated carbon.

Results

Characterization of the Prepared Activated Carbon

This section addresses the physical and chemical properties of the Date Frond activated carbon (DFAC) prepared in this study. The characterization includes the FTIR, surface area, pore structure, surface morphology, and Elemental composition.

FTIR Analysis

The FTIR spectra of Date frond powder (DFP) and Date frond activated carbon (DFAC) are displayed in Figure 1. The broad peak at 3475.24 cm^{-1} , which appears in DFP, is caused by the hydroxyl group; this suggests the presence of moisture that is eliminated by the activation process and vanishes from the DFAC spectra. An alkane (C-H) stretching vibration is responsible for the band at 3245.21 cm^{-1} in (DFP) spectra. This spectrum's peak fading in DFAC suggests that hydrogen was removed during the activation process. The bands that first emerged in the DFP and DFAC spectra at 2034.24 cm^{-1} and 1724.82 cm^{-1} , respectively, are caused by skeletal C = C vibrations of

organics. The peaks in the spectra of DFP and DFAC are caused by carbon bond (C=C) bending vibration, and they are situated at 593.08 cm^{-1} and 570.7 cm^{-1} , respectively. The stretching of (-C-O-C-) has been attributed to the band at 1308.82 cm^{-1} in DFP. The (C-O) stretching band has been assigned in addition to the (C-H bend) and (C-H plane) stretching bands at 1176.68 and 956.32 cm^{-1} in (DFAC) [18].

Surface Area and Pore Structure

The BET surface area of the activated carbon prepared from Date fronds was found to be 320.07 m^2/g , with an average pore diameter of 4.1041nm, suggesting a porous structure suitable for fingerprint powder characteristics.

Surface Morphology and Elemental Compositions

SEM images (Figure 3a) show that the raw date frond powder possesses irregular shapes with no noticeable pores. In contrast, DFAC exhibits a spongy morphology with varied pore sizes and shapes, measuring approximately 48.49 nm in size. The activation process causes the volatilization of non-carbonaceous materials, resulting in the formation of heterogeneous pores. EDS analysis reveals a significant increase in carbon content from 57.38% in the raw material to 97.76% in DFAC, as shown in Figure 3. This increase in carbon purity enhances the DFAC's ability to reveal latent fingerprints on different surfaces through improved adhesion and contrast.

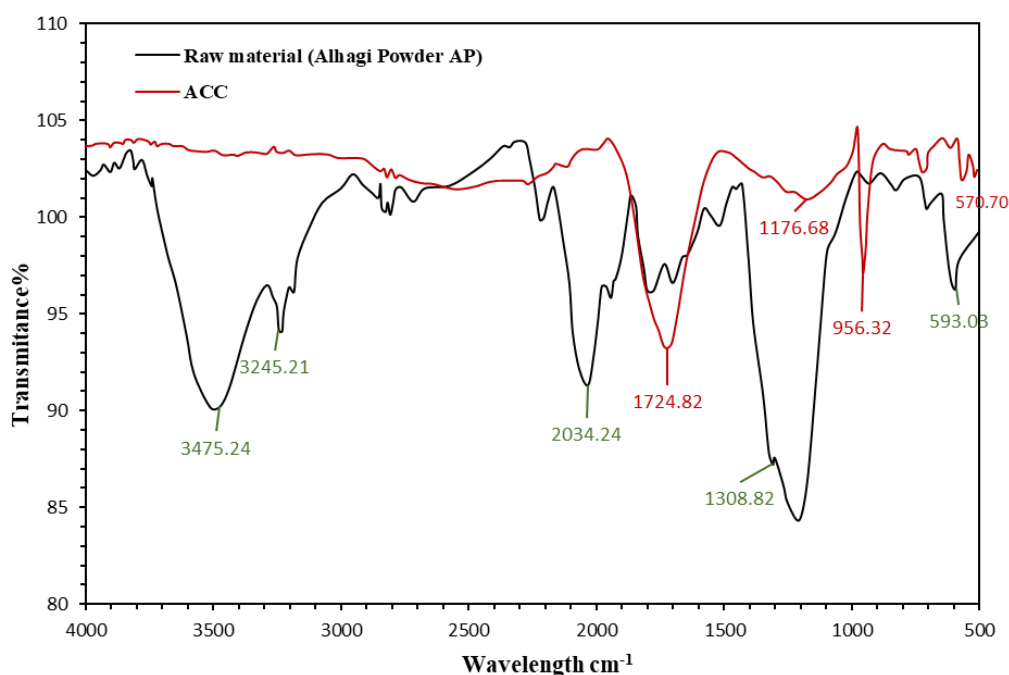


Figure 1. FTIR analysis of both Date frond powder (DFP) and Date frond activated carbon (DFAC).

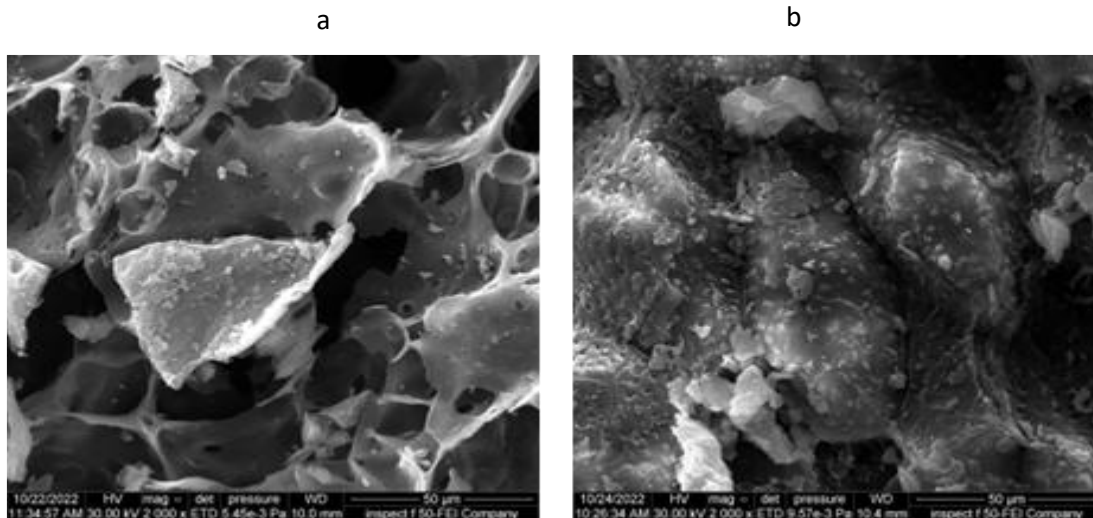


Figure 2. SEM image of (a) Date frond powder (b) Date frond activated carbon (DFAC).

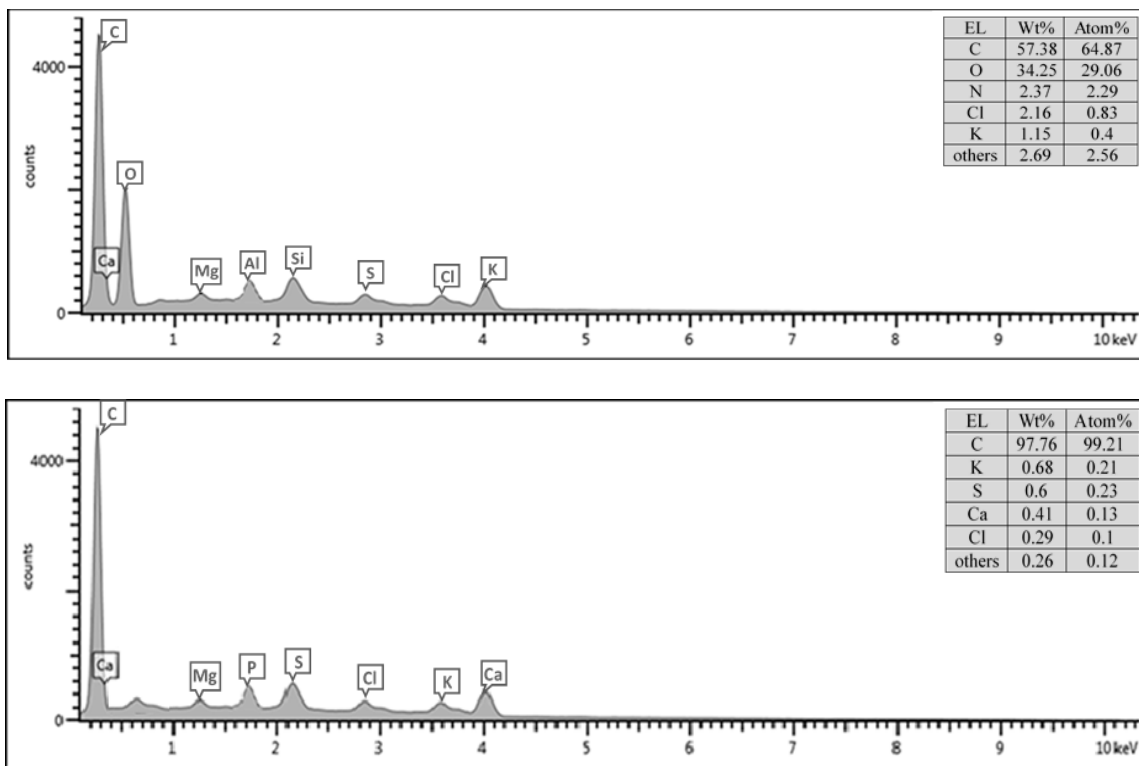


Figure 3. EDS analysis of (a) Date frond powder (b) Date frond activated carbon (DFAC).

Optimization of Activated Carbon Production

Using Central Composite Design (CCD) software, the study examined the effects of activation temperature (A), activation duration (B), and impregnation ratio on the yield of activated carbon (C). The yield percent % (Y%) values in the experiments were determined using Equation (1).

$$Y \% = \frac{\text{Weight of char}}{\text{Weight of precursor}} \times 100\% \dots \dots \dots (1)$$

The software CCD analyzes the input experimental data, taking into account all interactions between variables, and provides a quadratic correlation that calculates the predicted values of yield as indicated in Eq. (2). The values of experimental variables and the predicted values of yield are presented in Table 1.

$$Y\% = 81.21 + 8.13A + 0.968B - 3.51C - 0.509AB + 1.591AC - 3.882BC \dots \dots \dots (2)$$

$$-2.88A^2 - 2.49B^2 - 4.09C^2$$

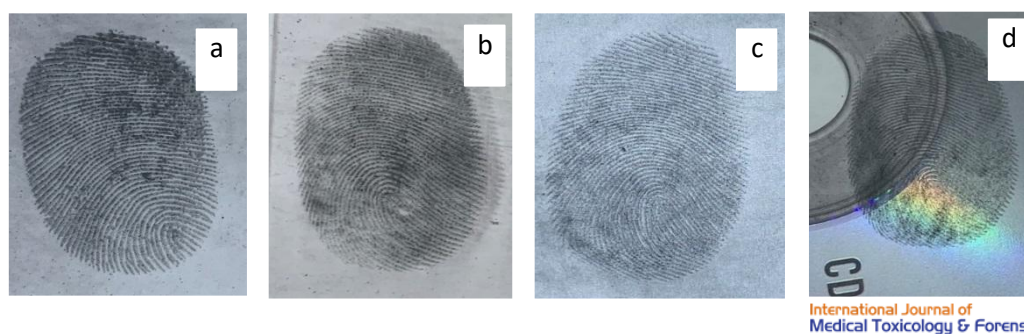


Figure 4. Visualization of the latent fingerprints by DFAC on several nonporous surface: (a) cardboard. (b) plain glass. (c) aluminum foil sheet. (d) the writable surface of the CD.

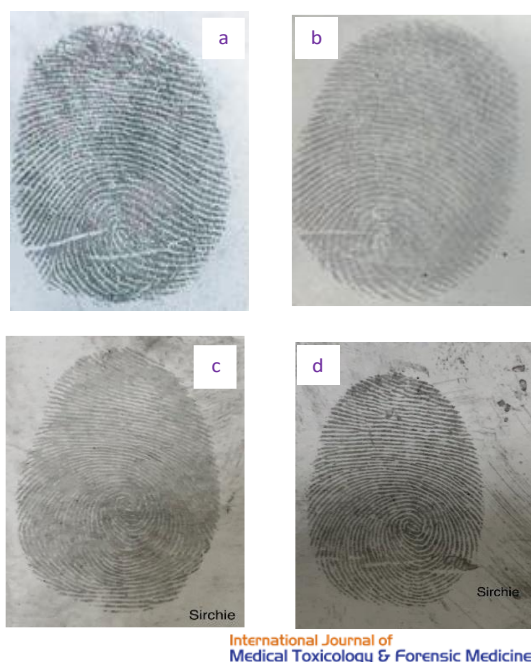


Figure 5. Showing comparative visualization of latent fingerprints between commercial and prepared powders- (a) prepared powder (DFAC) for males. (b) prepared powder (DFAC) for females. (c) commercial powder (Sirchie) for males. (d) commercial powder (Sirchie) for females.

As shown in Table 1, the optimal conditions were determined to be a 1:3 impregnation ratio, an activation temperature of 650°C, and an activation time of 2.5 hours, yielding a maximum yield of 86.14%. The derived response equation offers a quadratic correlation that predicts yield based on these parameters, confirming optimal conditions for DFAC production.

Development of Latent Fingerprints

Latent Fingerprint Development using DFAC

DFAC powder successfully developed latent fingerprints on several non-porous surfaces, including cardboard, plain glass, aluminum foil sheets, and the writable surface of CDs that are commonly found at

crime scenes.

Using the prepared Date Frond activated carbon (DFAC), latent fingerprints were developed on several non-porous surfaces, including cardboard, plain glass, aluminum foil sheets, and the writable surface of CDs commonly found at crime scenes. The results demonstrate the ability of the prepared DFAC to develop latent fingerprints on various surfaces, as illustrated in Figure 4.

Comparison with Commercial Sirchie Powder

Latent fingerprints from volunteers (male and female) were developed on cardboard surfaces using DFAC and the commercial Sirchie powder. Figure 5a and b show that both powders resulted in almost identical clarity and detail in the fingerprints, indicating that the DFAC performs comparably to widely used commercial fingerprint powders. The comparative outcome is displayed in Figures 5c and d. Both powders were found to produce prints that were almost identical in clarity and decipherability, displaying every nuance of the latent fingerprint.

Enhancement of Powder Quality with Additives

Adding sodium acetate (SA) to DFAC enhances powder adhesion to fingerprint ridges, as illustrated in Figure 6. Increasing the sodium acetate concentration from 5% to 20% significantly improves fingerprint visibility; however, using 25% SA results in poorer visibility. The optimal visualization was at 20% SA alone. Further, the combination of 20% sodium acetate and 2% mineral oil produced the best enhancement of fingerprint detail. Higher mineral oil concentrations (2.5%) reduced powder adhesion and cohesion, leading to lower visibility. The addition of sodium acetate to (DFAC) powder enhances powder adherence to the glass slide's friction ridges. Because the organic group (CH_3COO^-) is adsorbed onto the surface of the activated carbon, while the Na^+ ion functions as the cationic, sodium acetate improves powder quality [20].

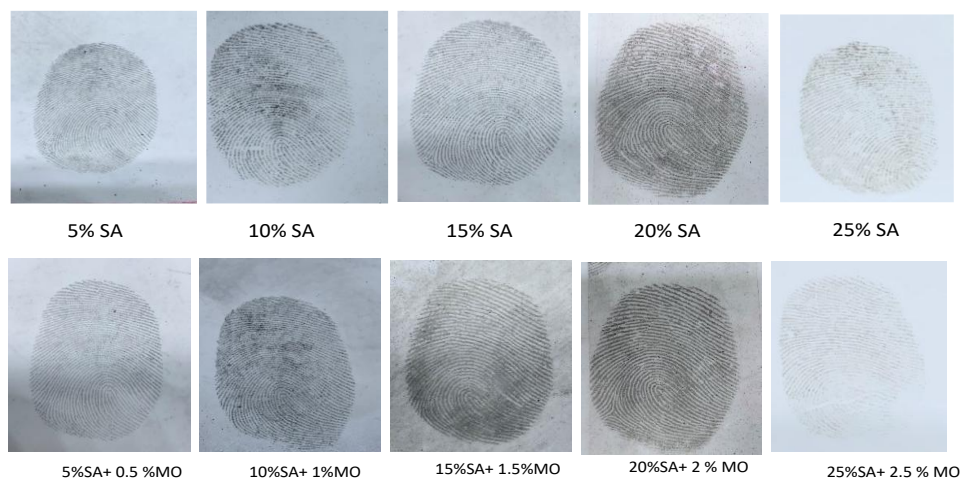


Figure 6. Showing comparative visualization of latent fingerprints on the nonporous surface (cardboard) at different quantities of additives of sodium acetate (SA) and mineral oil (MO).

Table 1. The predicted values of yield using CCD software.

RUNS	IR: A	TIME: B	TEMP: C	YIELD: R	RUNS	IR: A	TIME: B	TEMP: C	YIELD: R
1	2	2.5	650	80%	9	1.5	1.75	725	62.3%
2	2.5	1.75	725	80.24%	10	1.5	3.25	575	75.56%
3	2.5	1.75	575	79%	11	1.5	1.75	575	64.44%
4	2	1	650	68.04%	12	2	2.5	650	82.42%
5	1.5	3.25	725	54.66%	13	2	2.5	500	71%
6	3	2.5	650	86.14%	14	2	2.5	800	58.6%
7	2	4	650	74.36%	15	1	2.5	650	52.46%
8	2.5	3.25	575	85%	16	2.5	3.25	725	73.63%

This could cause a charge to develop on the activated carbon surfaces, causing moisture, salts, ionic chemicals, and polar substances to be deposited by a latent fingerprint. The addition of both sodium acetate and mineral oil to the activated carbon (DFAC) yields the best enhancement, specifically when the addition consists of 20% sodium acetate (SA) plus 2% mineral oil, as shown in Figure 6.

In contrast, the visualization quality decreases when

the mineral oil addition is 2.5%. The presence of a high amount of mineral oil in the recipe results in poor adherence of the powder to the friction ridges, as well as a loss of cohesion among the powder particles. The mineral oil adsorbed onto powder surfaces consists of two zones: an inner zone with polar parts directly bound to the polar components of the powder surfaces, and an outer zone with non-polar oil in contact with the oil components of latent fingerprints. This was consistent with what Mopoung and Thongcharoen [21] found

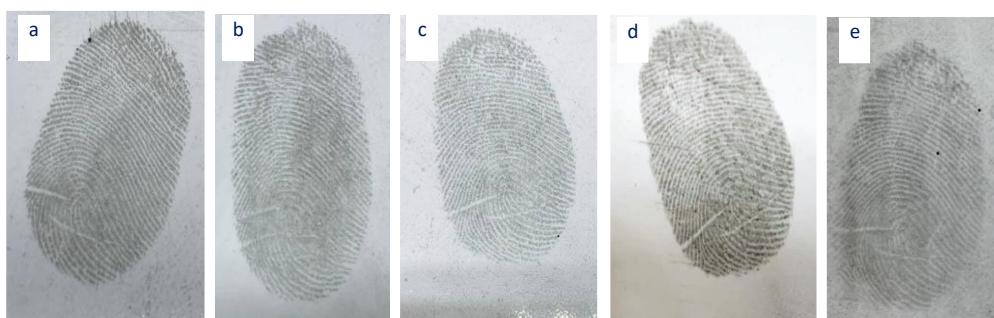


Figure 7. Showing comparative visualization of latent fingerprints on the nonporous surface (cardboard) at different lifespans. (a) after 1 day. (b) after 4 days. (c) After 7 days. (d) after 15 days. (e) after 25 days.

when studying the enhancement of the colored intensity of fingerprint powder obtained from banana peel-activated carbon by adding four quantities of sodium acetate, mineral oil, and methylene blue. An excess amount of mineral oil decreased the porosity of the carbon, reducing the potential for oil absorption on the latent imprint or the absorption of powder particles themselves. A better fingerprint image was obtained with 2% mineral oil and 20% sodium acetate, respectively, as shown in Figure 6.

Lifespan and Durability of Developed Fingerprints

In this study, the duration of the latent fingerprint's presence on the surfaces was also determined. For this, a non-porous surface (cardboard) was used, and samples were taken from the same volunteer under the same lab conditions each time. After 1, 4, 7, 15, and 25 days, the fingerprints were formed. As demonstrated in Figure 7, latent fingerprints found on the surface under examination can be developed successfully and remain there for extended periods; however, the quality of the prints decreases with increasing lifespan. As Figure 7 illustrates, the fingerprint remained visible for up to 15 days, but after 25 days, the contrast decreased.

Discussion

Preparation and Characterization of Activated Carbon

The study developed activated carbon from Date fronds by optimizing activation temperature, impregnation ratio, and activation time using Central Composite Design (CCD) [22, 23]. Characterization of DFAC by FTIR spectroscopy indicated removal of moisture and hydrogen during activation and the presence of carbon bonds essential for its functionality. The BET surface area of 320.07 m²/g and an average pore diameter of 4.1 nm confirmed a suitably porous structure for fingerprint adherence. SEM analysis showed the transformation from irregular raw powder to a spongy morphology with heterogeneous pores (~48 nm), while EDS demonstrated a marked increase in carbon content from 57.4% to 97.8%, enhancing powder purity and adhesive capability [24, 25].

Optimization of Activation Conditions

Using CCD, the yield of activated carbon was maximized at an impregnation ratio of 1:3, activation temperature of 650°C, and 2.5 hours activation time, achieving 86.14% yield. This robust optimization confirms the process's efficiency, providing a reproducible and cost-effective preparation method suitable for forensic applications [26, 27].

Development and Comparison of Latent Fingerprints

DFAC powder effectively revealed latent fingerprints on multiple non-porous surfaces such as cardboard, glass, aluminum, and writable CDs. Its performance was compared to the commercial Sirchie fingerprint powder, showing almost identical clarity and detail in fingerprint visualization, indicating that DFAC is a competitive alternative with comparable forensic reliability [28].

Enhancement with Additives

The study significantly improved fingerprint visualization by incorporating additives. Sodium acetate (SA) enhanced powder adhesion to fingerprint ridges through electrostatic interactions, with an optimal concentration of 20% yielding the best visibility. Mineral oil addition at 2% concentration further improved the detail due to its dual polar and non-polar interaction zones. Excess mineral oil (2.5%) impaired adhesion and cohesion, reducing print quality, likely due to pore blockage and decreased powder absorption capacity.

Longevity and Durability of Developed Prints

The durability of latent fingerprints developed by DFAC was evaluated on cardboard surfaces over 25 days. While clarity decreased over time, fingerprints remained clearly visible for up to 15 days, supporting DFAC's applicability in real forensic scenarios where prints may not be immediately recovered.

Broader Significance and Environmental Considerations

The study emphasizes the importance of an environmentally friendly and non-toxic alternative to conventional powders containing potentially harmful metallic or chemical components. DFAC, derived from agricultural waste (Date fronds), offers a sustainable forensic tool with minimal health risks, aligning with green chemistry principles [29, 30].

Acknowledgment

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Conflicts of Interest

The authors report there are no competing interests to declare.

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Data Availability

The data used is confidential.

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