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1,2-Indanedione (IND) Reagent for The Detection of Latent Fingermarks: A Review

استخدام كاشف (1,2-Indanedione IND) لاكتشاف علامات الأصابع الكامنة: مراجعة علمية

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Abstract

1,2-Indanedione (IND) is a chemical which is commonly used to detect latent fingermarks on dry, porous surfaces such as paper, cardboard etc. It interacts with amino acids of latent fingermarks and develops sharp, permanent, pink (also known as Joullie pink) colored fingerprints which are fluorescent in nature. It is an efficient and non-destructive approach to develop latent fingermarks. Standardized testing and validation of IND composition is suggested to improve the efficiency of this reagent to develop latent fingermarks on a wide range of surfaces of forensic importance.

المستخلص

يعد كاشف (IND 1,2-Indanedione) مادة كيميائية تستخدم بشكل شائع للكشف عن علامات الأصابع الكامنة على الأسطح الجافة المسامية مثل الورق العادي والمقوّى وما إلى ذلك، حيث يتفاعل هذا الكاشف مع الأحماض الأمينية لعلامات الأصابع الكامنة ويشكل بصمات ملونة حادة ودائمة ووردية (Joullie pink) ذات طبيعة فلورية. وتعد هذه الطريقة فعالة وغير مدمرة بهدف تشكيل وكشف بصمات الأصابع الكامنة، ودائمًا ما يُقترح القيام بالاختبارات المعيارية واختبارات التحقق من موثوقية وصحة تركيب كاشف (IND) لتحسين كفاءة نتائج كشف بصمات الأصابع الكامنة على مجموعة واسعة من الأسطح ذات الأهمية الجنائية.

Keywords: Forensic Science, Latent Fingerprints, 1,2-indanedione, Amino Acids, Porous Surfaces.

الكلمات المفتاحية: علوم الأدلة الجنائية، بصمات الأصابع الكامنة، 1،2-إندانيديون، الأحماض الأمينية، الأسطح المسامية.

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1. Introduction

Fingerprints, due to their uniqueness, are one of the most important features of human identity that are used to identify a person. Different methods are frequently used to develop latent fingermarks (LFM) on a variety of substrates at crime scene [1-6]. 1,2-Indanedione is an amino acid sensitive chemical that is used to detect fingermarks on dry porous surfaces [7].

Fingermarks may be left on any surface or object present at a crime scene. They provide direct connection to suspect and can be used to establish their identity with certainty and to link suspect with weapon or crime scene. Fingermarks are formed by the deposition of perspiration released from sweat pores present on friction ridge skin of fingers. Since sweat is colorless, therefore, the impressions formed from them are also colorless and invisible to the human eye. These impressions are called as LFM [8-10].

Sweat glands especially, apocrine and eccrine glands, exudates the perspiration from fingertips. Several eccrine glands are present on the palms of hands. More than 98% water is present in the perspiration secreted from these glands. Variety of organic and inorganic components are secreted from these glands due to metabolism. Eccrine sweat contains amino acids, lactic acid, proteins, urea, uric acid, sugars, creatinine and choline while fatty acids, glycerides, wax esters, squalene and sterol esters are the major components of sebaceous secretion [11-13].

The constituents of human perspiration can be categorized into two main groups: hydrophilic and hydrophobic [14]. The amino acids and inorganic ions belong to hydrophilic group. 1,8-diazafluoren-9-one (DFO), 1,2-Indanedione (IND) and Ninhydrin (NIN) based methods react with these hydrophilic constituents of perspiration and form color compounds. The fats, lipids and proteins belong to hydrophobic group. This hydrophobic group can be further sub-categorized into labile and robust fractions depending on their stability in air and water. The fatty acids (saturated and unsaturated), lipids and triglycerides belong to labile fraction while proteins and lipo-proteins belong to robust fraction of hydrophobic group. The constituents of labile fraction are sensitive to air but not to moisture. However, the constituents of robust fraction retains for long time on the surface of paper because they form strong hydrogen bond with cellulose of paper. Oil Red O (ORO) targets the labile while physical developer (PD) targets the robust fraction of latent fingermark residues [8, 15]. Figure-1 represents the classification scheme to develop different fractions of latent fingermark residues.

Wide range of optical, physical and chemical methods are frequently used to detect LFM on a variety of surfaces of forensic importance. Optical methods use electromagnetic radiations of appropriate frequency for this purpose and are non-de-

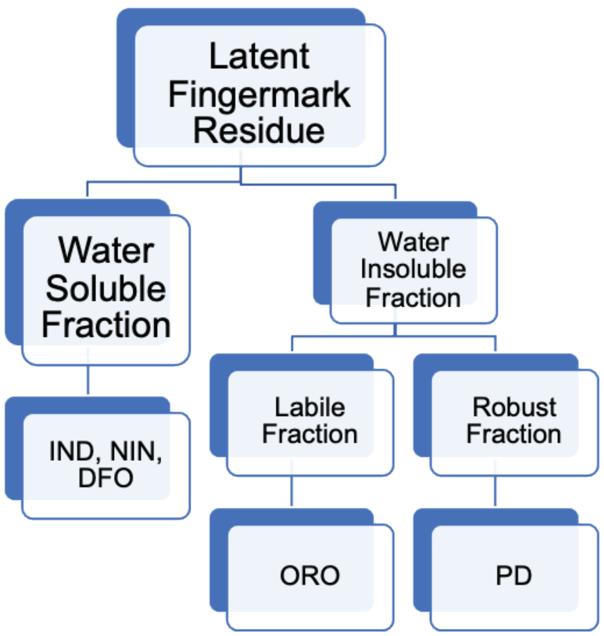

Figure 1- *Classification scheme to process different fractions of latent fingermarks (IND- 1,2-Indanedione; NIN-Ninhydrin; DFO- ,8-diazafluoren-9-one; PD-Physical Developer; ORO-Oil Red O).*

structive. In physical methods, fine particles of powder composition gets adsorb to fatty acids and oils present in residues of LFM residues and render them visible. Chemical methods involve the chemical transformation of a specific component of sweat into a colored derivative. These methods can be used alone or in a definite sequence to improve the visibility of developed fingerprints. The selection of a particular method varies with type, color, condition and texture of surface on which LFM is impinged [1-6, 8].

IND reacts with amino acid contents of LFM. It is a fluorescent reagent that is used to develop LFM on dry, porous surfaces including thermal papers, due to its high sensitivity towards amino acids [16-20]. In 1958, IND (1,2-diketohydrindene) was first synthesized by Cava and co-workers [21]. However, in 1997, Dr. Joullie's research group from University of Pennsylvania and Ramotowski research group from the U.S. Secret Service recognized its use as a fingerprint reagent. 5-Methylthio-IND was the first derivative to be synthesized. A total of eight derivatives of IND were synthesized and tested [18].

2. The Reagent

IND is sensitive towards amino acid fraction of LFM residues. It is a NIN analog. Empirical formula of IND is C9H6O2 and its molecular weight is 146.145g/mol [22]. The structure of IND is depicted in Figure-2. IND is used primarily for fluorescence detection of LFM on dry, porous surfaces [23]. IND interacts with α-amino acids and produces Joullie Pink (JP) which gives excellent luminescence without any post-treatment [24]. 1,2-Indanedione-Zinc chloride (IND-Zn) gives fluorescent fingerprints after reacting with LFM, in a single step without requiring any subsequent post-treatment [25-27].

Petrovskaia et al., [28] discussed the mechanism of reaction between amino acids and IND

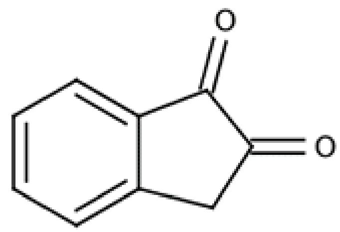

Figure 2 - *Structure of 1,2-Indanedione (IND) 3H-indene-1,2-dione ($C_9H_6O_2$).*

and its derivatives. The two process starts with the formation of an imine followed by decarboxylation and subsequent formation of 2-amino-1-indanone which reacts with another molecule of IND and develops pink color (Figure-3). This pink color compound is also called "Joullie Pink" (JP) in the honor of its inventor [29]. Alaoui et al., [30] reported the formation of fluorescent 2-carboxymethyliminoindanone and 1,2-di(carboxymethylimino)indane on reaction of IND with glycine in methanol.

Generally, IND-Zn formulation contains IND, glacial acetic acid, petroleum ether and zinc chloride. IND reacts with amino acid contents of LFM deposits on paper or other porous surfaces. Glacial acetic acid is used to reduce the alkalinity of paper. It was observed that addition of acetic acid to IND formulation did not improve the quality of developed prints. However, it had unfavorable effect on the quality of developed prints [31, 32]. Zinc chloride (zinc ions) acts as a catalyst in reaction of IND with amino acids content of LFM and reduce the need of high levels of relative humidity for the formation of reaction product [33, 34]. The yield of JP and its fluorescence intensity varied with presence of humidity and zinc ions. Zinc ions increase the yield of JP and hence fluorescence of reaction product by stabilizing the reaction intermediate after interacting with it while the presence of high humidity decreases the yield of JP and thereby fluorescence of reaction product. However, in high humid conditions, rate of degradation of JP product

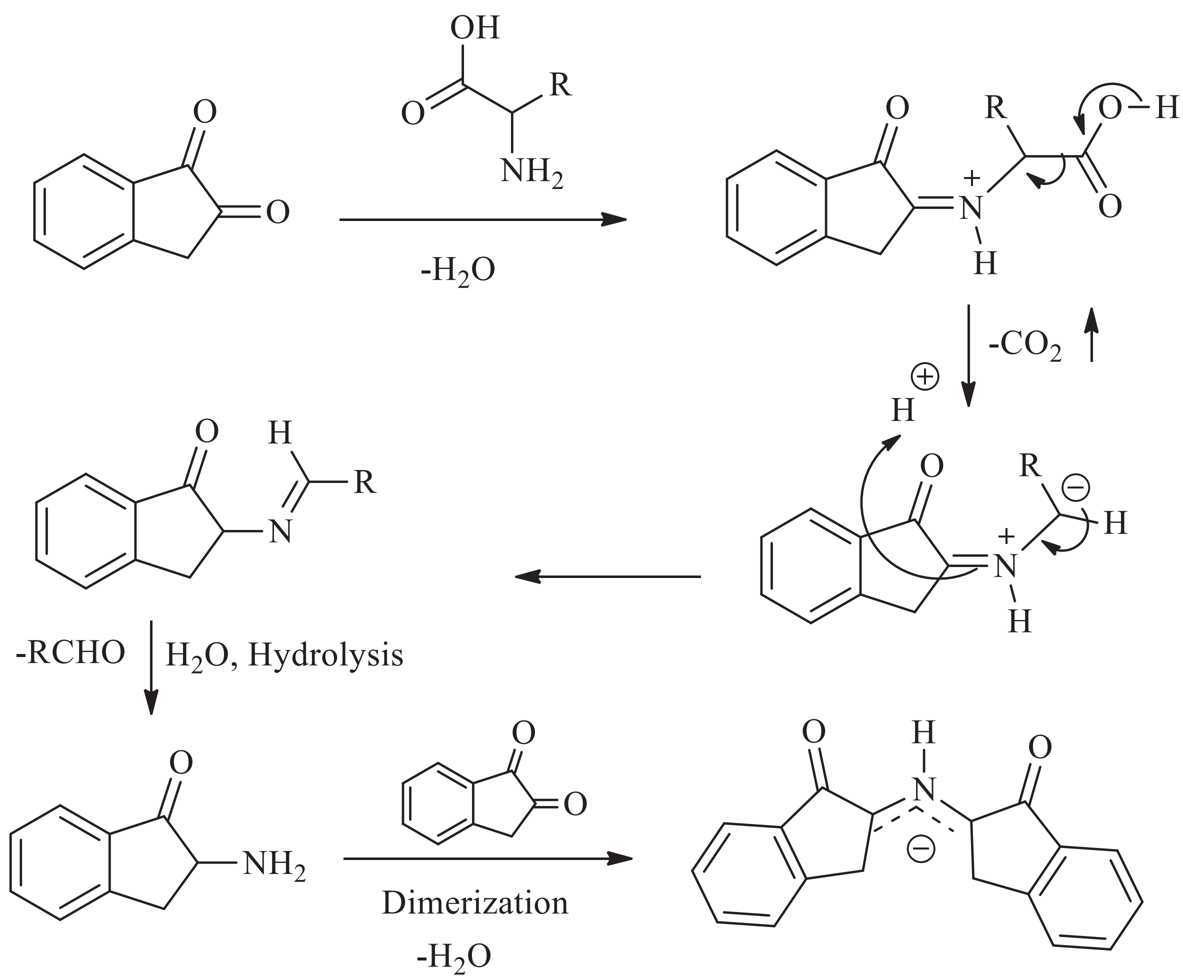

Figure 3- *Proposed reaction mechanism for 1,2-indanedione with amino acids.*

decreases in the presence of zinc ions. It is due to the formation of stable complex between JP ligand and cellulose matrix through hydrogen bonding in the presence of zinc ions. Cellulose substrate have stabilizing effect on JP product and, therefore, retarding its degradation [24, 35]. The presence of zinc ions in IND formulation improves the stability of resultant complex and subsequent quality of developed prints [35, 36]. Presence of zinc chloride in high concentration enhances the luminescence of developed prints. However, an excess amount of zinc chloride in IND formulation causes decrease in luminescence and color intensity of developed prints and also decreases shelf life of IND working solution [37, 38]. The performance of HFE 7100 based IND formulation could be enhanced by adding small amount of zinc chloride into it. Addition of zinc chloride to formulation reduces its sensitivity towards environmental moisture [25]. It was observed that intensity of luminescence of developed prints increase with concentration of zinc chloride [39]. Post-processing with zinc salts improves the luminescence of IND developed fingermarks [18-20, 24, 35, 40]. It was noted that type and concentration of carrier solvent, used in formulation, affects the fluorescence intensity of developed fingermarks. HFE 7100 was observed to be the most effective carrier solvent [40]. Fitzi et al., [41] recommended HFE 7100, as a carrier solvent, in IND-Zn formulation to avoid background blackening of surface during the development of LFM on thermal papers. In a similar study, Wallace-Kunkel et al. [36] recommends the use of HFE 7100 over petroleum ether based IND formulation to develop LFM on fluorescent (green and yellow) and thermal paper, untreated wood, and wallpaper. In another study, use of HFE 7100 based IND solution was recommended to detect LFM on thermal papers without changing the color of thermal paper [17]. Olszowska et al., [42] suggested the use of trans-1-chloro-3,3,3-trifluoropropene in place of HFE 7100 in IND formulations due to its high wetting index, cost-effectiveness, very low potential towards global warming. Use of ethyl acetate in place of alcohols was recommended in IND formulations. It was observed that IND reacts faster than DFO. The optimum formulation consists of 7% ethyl acetate and IND solution (0.2%) in HFE 7100 [32].

The use of dichloromethane based IND formulation was suggested when ink was present on paper [43].

Shelf life of working solution of IND-Zn was reported to atleast one week to 3 months whereas shelf life of stock solution of IND-Zn was 12 months [35, 44-46]. Presence of ethanol in petroleum ether based IND-Zn formulation increases its shelf life [38].

3. Methodology

Development of LFM with IND or IND-Zn method is simple and fast. Stock solutions of IND and zinc chloride are necessary to develop LFM on dry, porous surfaces. Appropriate amounts of these stock solutions, of optimum concentrations, are mixed together in a carrier solution to form working solution which is used to develop LFM [8].

Reagent Preparation:

a. IND stock solution: It is prepared as follows:

Dissolve 4 g of IND in 450 mL of ethyl acetate and 50ml of glacial acetic acid and store this solution in a dark glass bottle [8, 47-49].

b. Zinc chloride stock solution

Dissolve 8 g of zinc chloride in 200 mL of absolute ethanol. Store this mixture in dark glass bottle [8, 47-49].

c. IND-Zn working solution

Mix 50 mL of stock solution of IND with 2 mL of stock solution of zinc chloride and add 450 mL of HFE 7100 to it. The final working solution should be mixed thoroughly and prepare immediately before use [8, 47-49].

Test Procedure: LFM can be developed on porous surfaces by following a series of steps:

- The object possessing the latent impressions is dipped in the IND-Zn working solution for 1min.
- Remove the article from this solution and dry it in a fuming hood.
- Object can be heated with a steam press operated at 165°C for 10s.
- Pink-colored fingermarks develop on surface of article.
- Developed fingermarks can be viewed and photographed under white light and in the fluorescence mode using illumination with blue-green light (460-510nm) through orange 549nm filter [8, 22, 23, 47-50].

IND-Zn developed prints can be viewed in absorption or photoluminescence mode. The absorption spectrum of IND-Zn developed prints showed maximum absorption at around 550nm. Use of bandpass filter with a central wavelength between 500 and 560nm improves contrast of developed prints in absorption mode. In photoluminescence mode, excitation (490 to 560nm) and emission (550 to 620nm) bands of IND-Zn developed prints are broad. The photoluminescence spectrum of IND-Zn developed prints showed one maxima at 515nm and a main excitation peak at 550nm while maximum emission at 560nm and a second peak at around 590nm [45]. In addition to this, alternate light source (ALS) with illumination at 530nm and Schott OG550 emission filter can be used to visualize fingerprints developed with IND-Zn processing [31]. The use of solid state Nd:YVO4 laser over MiniCrime Scope and Polilight was suggested to visualize the prints developed with IND-Zn method [46]. Dalrymple and Almog [51] used lasers and broadband (LED's) sources to detect and visualize fingerprints, developed with IND-Zn, on brown wrapping paper and white bond paper.

It was observed that environmental conditions affect the products sensitivity and thereby the fluorescence of developed prints [36, 52, 53]. Performance of IND processing depends upon the presence of relative humidity whereas performance of IND-Zn processing is independent of presence of relative humidity [25, 46]. It was also observed that IND-Zn formulation was less reliant on the relative moisture content of treated latent prints. No significant differences were observed on the performance of IND-Zn at different relative humidity conditions [25]. If ambient relative humidity was lower than 70%, NIN developing conditions (80°C, 65% RH) were used while DFO development conditions (i.e., 20 min at 100°C) were used when it was higher than 70% [35].

Ponschke and Hornickel [44] observed that quality of developed prints could be improved by leaving them to develop for 24h in dark at 50% relative humidity. Papers were sprayed, using plastic spray bottle, with IND solution in a fume hood and left to develop for 24h in dark at 50% relative humidity [44]. Frick et al., [54] air dried the processed sample before heat treatment with Elna laundry press (set at 1600C) for 10s [54]. Smith et al., [31] developed LFM on envelopes by leaving them to develop for 24hr in clean closed container in hood after processing with IND solution. In a similar study, Holt [45] developed LFM on envelopes by providing heat, to IND processed envelopes, using an iron (set at 1600C) for 10s. Paper towel was placed on top of envelope to prevent burning of envelope. Schwarz and Hermanowski [55] developed LFM on thermal paper by providing heat, to IND processed thermal paper, using an iron (set at 1600C) for 10s. Active layer of thermal papers stained dark when treated with IND-Zn and further heating accelerates this staining and thereby reducing the contrast of developed prints. In a similar study, use of air drying in fume hood for 24h was suggested as an alternative to heat to develop LFM on IND processed samples [56]. Some studies recommended the use of heat press, operated at 120-165°C for 10-15s, over conventional oven heating [36, 40]. Development at 80-1000C for 10-30min with 60-65% relative humidity was also suggested [22, 23, 32]. Figure-4 illustrates the fingerprint developed with IND on black sheet.

4. Evaluation of 1,2-Indanedione (IND) Method

Almog et al., [22] synthesized and evaluated IND and its mono- and dimethoxy derivatives for developing LFM on paper as these compounds form fluorescent products with amino acids contents of LFM residues. It was observed that structural modifications such as substitutions at position 3, removal of the benzene ring or increase in number of carbon atom from five to six in a ring, affects the intensity of fluorescence [22]. IND and its substituted derivatives produced pink color with glycine on paper. This pink color product produced strong fluorescence without secondary metal salt treatment at room

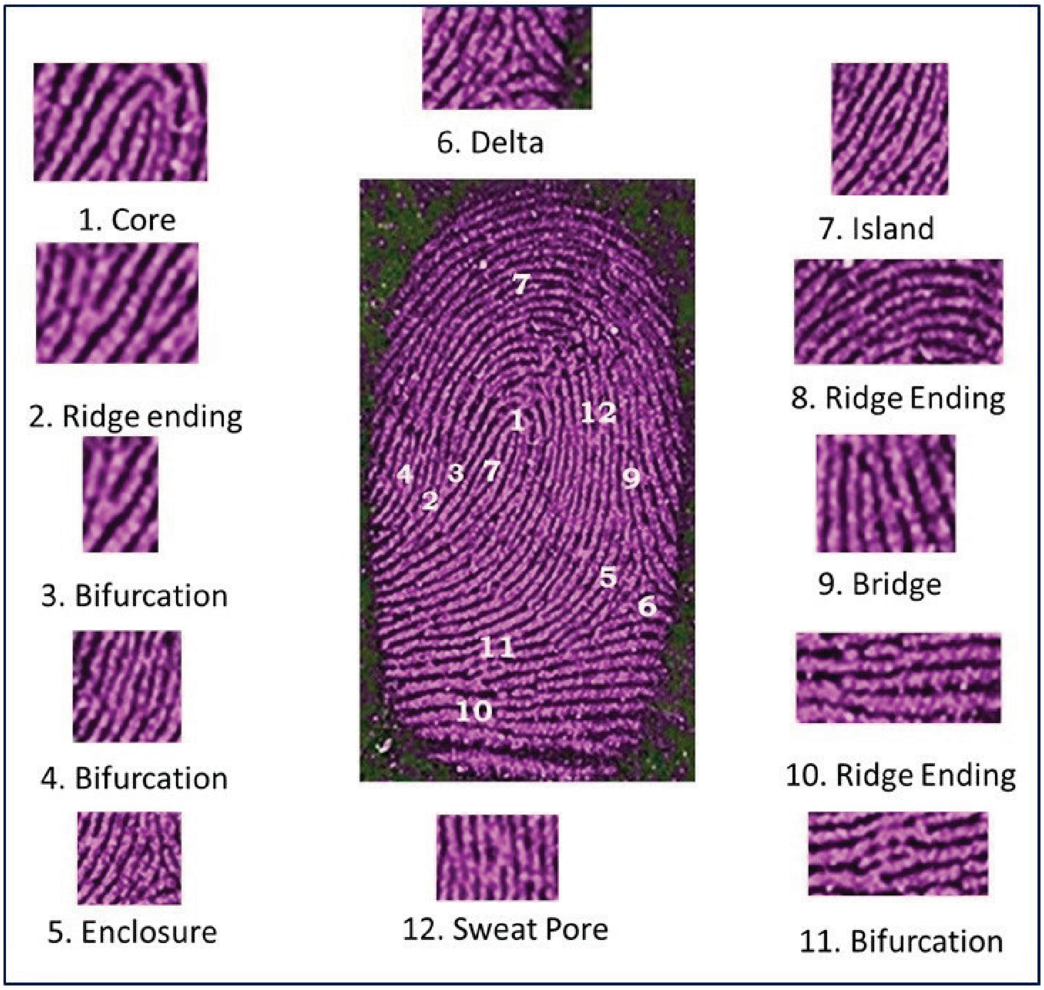

Figure 4- *Fingermark developed with IND on black sheet.*

temperature. 5,6-dimethoxy-IND was the most effective compound as it produced very strong fluorescence (without zinc salt treatment) comparable to DFO. However, treatment of 5,6-dimethoxy-IND developed prints with zinc salt enhanced the sensitivity and fluorescence of prints [18, 19]. Roux et al,. [40] used IND and 5,6-dimethoxy-IND to develop LFM on porous surfaces. The limits of detection of both INDs were 7.6 × 10–5 mg/mL. Wilkinson [57] studied IND using mass spectrometry and nuclear magnetic resonance spectroscopy and observed that IND formed stable hemiketal when dissolved in methanol. However, formation of this hemiketal diminished the reactivity of IND towards amino acids and, therefore, use of methanol should be avoided in preparing IND formulation as a fingerprint reagent [32, 57]. Alaoui et al., [58] studied the reaction product of IND with alanine in methanol and observed that pale pink color of IND developed fingerprints on papers was also present in IND-alanine methanol solution. It was observed that addition of zinc into IND-alanine solution or post-processing of IND developed prints with zinc improves the intensity of fluorescence of developed prints. However, no emission enhancement was observed on adding europium salt even after the formation of IND-alanine-europium complex. The intensity of luminescence of prints post-treated with europium salt was less in comparison to with zinc salt. Lennard et al., [59] studied the reaction mechanism of IND with different amino acids and observed that colors and their fluorescence intensities varies with amino acids. Hong and Han [60] used IND composition to develop LFM on fired cartridge casings. IND-L-alanine (IND-ALA) complex was synthesized and used to enhance the quality of developed prints but its use was proved to be ineffective.

Stimac [16] used indanediones to develop LFM on carbonless and thermal papers. In another study, Stimac [17] used HFE 7100 based IND formulation to develop LFM on thermal papers. Chen et al,. [61] recommended the use of modified IND formulation to develop LFM on text-printed thermal papers without any need to heat them. Ponschke and Hornickel [44] used IND to develop fresh and 30 days old LFM on different types of thermal papers and prescription labels. Wiesner et al,. [32] used IND to develop LFM on bank cheques. Stoilovic and Lennard [62] used HFE 7100 based IND-Zn composition to develop LFM on thermal paper.

Almog et al., [22] used IND to develop LFM on paper due to its ease of preparation, good solubility in non-polar (petroleum ether and Freon 113) solvents and high sensitivity in comparison to DFO. Lee and Joullie [63] developed sensitive and efficient IND functionalized gold nanoparticles as a bi-functional reagent for developing LFM on paper. This reagent could detect eccrine as well as sebum-rich latent fingermark residues on paper. In a similar study, Lee and Joullie [64] developed fast and efficient optimized protocol for the development of LFM on paper using 1,2-indanedione based bi-functional reagent. D'Elia et al. [37] used petroleum ether, HFE 7100 and methanol and HFE 7100 based IND-zinc chloride formulations to develop fresh and 120 days old LFM on white paper. HFE 7100 based formulation gave best results. IND-Zn was used to develop LFM on white copy paper [54]. It was noted that performance of IND-Zn to detect LFM depends on amount of eccrine material (e.g. amino acids and salts). Low amounts cause poor development of LFM [54]. Smith et al. [31] used IND to develop aged (16 to 21 years old) LFM on envelopes. It was observed that reactivity of IND towards amino acids of LFM was more than NIN. Prints developed with IND do not fade as rapidly as prints developed with NIN. The use of IND as primary detection method to develop LFM on porous surface was advocated [31].

Gardner and Hewlett [53] used IND to develop LFM on porous surfaces including envelopes, newspapers and train tickets. Holt [45] used IND-Zn to develop LFM on envelopes sent through postal system. It was noted that process of postal distribution did not affect the quality and sustainability of LFM deposits on envelopes. IND-Zn is an effective and sensitive method to develop LFM on porous surfaces. Serrano and Sturelle [38] developed an optimized petroleum ether based IND-Zn formulation to develop LFM on newspaper, kraft paper and white printer paper. It was observed that developed formulation can be used in place of DFO or NIN to develop LFM on kraft paper, newspaper, and white printer paper. In another study, petroleum ether based IND-Zn formulation containing 7.4% v/v zinc chloride gave best results on both fresh and aged (11 years old) LFM. It was observed that color and fluorescence developed with this optimized formulation was superior than DFO treated prints [35]. Spindler et al. [34] observed significant variations in the visible and luminescence spectra of products formed by reaction of IND with 9 different amino acids (alanine, glycine, histidine, leucine, lysine, ornithine, serine, threonine and valine) on cellulose coated white copy paper, plastic backed thin layer chromatographic plates and ashless filter paper. Pretreatment with humidification of amino acid spots prior to IND processing significantly improved the results and thereby suggested that presence of moisture plays key role in efficient fingermark development. However, remarkably consistent visible and luminescence spectra of products formed by reaction of IND-Zn with these amino acids were observed on these surfaces.

Hong et al., [65] developed and used 8% polyvinylpyrrolidone (PVP) in combination with IND and zinc chloride to develop LFM on thermal sensitive and non-sensitive surfaces of 12 different types of thermal papers. Performance of this formulation was found to be better on thermally sensitive surface in comparison to its thermally non-sensitive surface. The use of commercially available amino acid and sebaceous oil based fingermark simulants (as quality control standards) was not recommended to evaluate IND, NIN, ORO and PD due to significant differences observed between these commercially available simulants and LFM in response to fingermark development reagents [66]. In some studies, it was noted that quality of fingerprints, developed with IND-Zn method, vary significantly with age of donor and latent fingermark. In addition to this, a statistically significant difference was observed between fingermark samples treated and graded within 3 days of deposition to those treated after 1 month. However, no significant variations were found between quality of developed fingerprints and gender of donor and food consumption and recent application of cosmetics. It was observed that recent consumption of food rapidly degrades the treated and untreated amino acids [47, 48].

4.1. Post-Treatment Procedures

Post treatment with zinc chloride enhances the fluorescene of fingerprints developed with IND formulation [18, 35, 36]. However, in contrast to this, Almog et al., [22] observed that post-processing with zinc chloride did not improve the fluorescence of fingerprints developed with IND formulation. Schwarz and Hermanowski [55] used G-3 to enhance the contrast of IND-Zn developed prints on thermal papers by discoloring the dark staining produced during treatment with IND-Zn. Serrano and Sturelle [38] suggested the use of NIN method to enhance the quality of fingerprints developed with IND method.

4.2. Sequential Studies

Frick et al. [54] advocated the sequential use of IND-Zn and PD to maximize development of available LFM on copy paper. In another study, due to high efficiency, improved quality of developed prints and non-interference between techniques, sequential processing with IND, propylene glycol based ORO reagent and PD was recommended to develop LFM on white copy paper [50].

Sequential use of IND and NIN was suggested to enhance the success rate of developing LFM on thermal papers [61]. Boudreault and Beaudoin [67] used sequential treatment with IND-Zn followed by NIN to develop fresh and aged (11 weeks old) LFM on different kinds of porous, semi-porous or non-porous surfaces such as standard white paper, thermal paper, recycled paper, black plastic bag, aluminum foil, duct tape and transparent plastic bag. It was noted that method of processing and nature of surface affects the quality of developed fingerprints over time. It was also observed that fingermarks developed with IND-Zn degrade significantly over time on porous surfaces [67]. It was observed that detection rate could be improved by progressing from DFO and NIN to IND chemical processing on envelopes [31]. Sequential use of IND-Zn → NIN over DFO → NIN was suggested to develop LFM on paper as less difference was observed in reactivity between IND and NIN as compared to between DFO and NIN [68]. Sequential processing with DFO → IND-Zn over IND-Zn → DFO was suggested [35]. Marriott et al,. [69] recommended the sequential processing with IND-Zn → NIN → PD to develop LFM on common papers. Use of IND-Zn sequence over DFO sequence was suggested for processing different kinds of papers. In comparison to DFO, IND-Zn developed better quality fingermarks and sequential processing with NIN improves the quality of prints developed with DFO and had negligible effect after IND-Zn processing. Negligible difference was observed in performance between the two sequences across different kinds of papers and different time periods evaluated.

Deschamps [70] advocated the use of sequential processing with cyanoacrylate fuming and IND-Zn or NIN to develop LFM on tissue paper side of the carbon paper. The sequential processing with cyanoacrylate fuming followed by IND-Zn or NIN followed by RAM dye stain was recommended to develop LFM on pigmented side of the carbon paper. The sequential use of IND-Zn, heat and G3 was recommended to develop LFM on thermal papers in less than 10 min [55].

4.3. Comparative Studies

IND can be used to replace NIN in reagent sequence for developing LFM on thermal and carbonless papers [16]. Due to increased detection rate, reduce heating time, less toxicity and inflammability, cost-effectiveness and high sensitivity of IND, use of IND in place of DFO was suggested to develop LFM on white copy paper, magazines, junk mail, newspaper, envelopes, thermal and carbonless papers [16, 22, 37, 42]. In 2004, Wallace-Kunkel et al. [71] reported that 14% of laboratories used IND in routine casework samples and 60% of these advocated the superiority of IND over DFO. The use of IND over DFO and NIN was suggested to develop LFM on used train tickets, thermal paper, untreated wood, wallpaper, and fluorescent paper due to its higher sensitivity than DFO and NIN [36, 56]. In a similar study, the use of IND over NIN and DFO was advocated to develop aged (16 to 21 years old) LFM on envelopes [31]. The replacement of DFO with IND-Zn as standard fingerprint development technique was suggested [36]. Due to their lower detection limits for glycine, cost-effectiveness and superior luminescence of developed prints, use of IND-Zn and 5,6-dimethoxy-IND-Zn over DFO was recommended to develop LFM on porous surfaces [18,19, 40].

Lam and Wilkinson [46] suggested the replacement of DFO with IND-Zn to develop fresh and 84 days old LFM on variety of porous surfaces such as lined paper, brown kraft paper, white envelopes and paper, paper currency, newsprint, recycled envelopes and used checks. The fingerprints developed with IND-Zn produce brighter fluorescence than those developed with DFO [46]. In another study, Stoilovic et al. [25] suggested the use of IND-Zn over DFO for developing latent prints on paper. Wilkinson et al. [72] advocated DFO over IND to develop LFM on porous surfaces. PVP based IND-Zn formulation was observed to be superior to NIN and DFO methods to develop LFM on heat sensitive side of thermal papers. However, this composition was found unsatisfactory for developing LFM on heat insensitive side of thermal papers [65].

Wiesner et al., [32] observed that IND developed more number of LFM than sequential processing with DFO followed by NIN on bank cheques. Sears et al. [73] recommended the use of IND-Zn in place of DFO to develop LFM on magazine paper, newsprint and brown paper. In contrast to this, Merrick et al. [52] advocated Freon 113 and HFE 7100 based DFO formulations over IND to develop LFM. Chan et al,. [74] advocated IND- Zn, DFO and NIN over Isatin-zinc chloride to develop LFM on white copy paper. Sensitivity and luminescence generated by IND-Zn is greater than Isatin. LOD of IND- Zn was 0.1×10^{-6} M. Solvents used in the preparation of IND-Zn formulation was safer than those used in optimized Isatin formulation. Frick et al,. [54] observed that IND- Zn and PD are complementary techniques to each other as both techniques target different fractions of latent fingermark residues.

Mostowtt et al., [23] recommended the use of IND-Zn over Thermal Fingerprint Developer-2 (TFD-2) to develop fresh and 84 days old LFM on brown kraft paper, post newspaper and white copy, legal and notebook papers. The use of TFD-2 prior to IND-Zn treatment was not recommended as it negatively affect quality of prints developed with later method. In a similar study, despite the rapid, simple and easy heat application provided by TFD-2, the use of IND-Zn over TFD-2 to develop LFM on brown and white copy papers, recycled paper, brown wrapping paper, glossy paper and thermal paper was suggested due to low sensitivity and poor contrast of fingerprints developed with TFD-2. The use of TFD-2 was not recommended for developing LFM when conventional methods are readily available [49]. In a similar study, use of IND over TherMaNin was advocated to develop LFM on variety of thermal papers [44]. Goel [75] suggested the use of IND-Zn dry contact method over hot print system to develop LFM on thermal paper because IND-Zn dry contact method provides stable, better-quality prints.

The use of wet contact method over dry contact method, for IND processing, was advocated due to its high sensitivity [50]. In wet contact IND processing, prints were developed by dipping the paper lighly in working solution, air dried and heated for 10s with Elna laundry press operated at 1600 ^{o}C [62]. Patton et al,. [20] reported an easy and non-destructive dry contact method to develop LFM on thermal paper with IND-Zn. In dry contact IND-Zn processing, thermal papers were placed in between two processing papers (impregnated with reagent) and were preserved in plastic bag in dark lightning conditions without any heat treatment for 24 to 36h.

4.4. Effect of 1,2-Indanedione processing on chemical composition of latent fingermarks residues

Koenig et al., [43] noted that processing of LFM with IND effects its initial composition. Dichloromethane based IND formulation reduced the amount of cholesterol and squalene by half in LFM residues whereas HFE 7100 or methanol based IND formulations did not significantly affect the initial composition of LFM residues. It was observed that IND processing introduced some additional compounds such as napthalenone and benzenamine. Therefore, specific recommendations should be made when chemical analysis may be performed after processing with IND. In IND method, compounds dissolved in working solution from the previous samples may interfere with subsequent samples and thereby causes cross-contamination. Therefore, processing of samples in different solutions was suggested to avoid contamination. Mangle et al,. [68] used liquid chromatography-mass spectrometry to determine the concentration of amino acids after treating with IND-zinc chloride and NIN.

4.5. Effect of 1,2-Indanedione processing on DNA analysis

Azoury et al., [76] reported that IND did not affect the isolation and amplification of STRs examined and therefore, DNA could be successfully typed from such processed items. No variations were observed in the STR profiles generated from processed and unprocessed envelopes and stamps.

It was observed that no DNA could be recovered six days following IND processing as the success of DNA extraction depends on the time lapse between IND treatment and DNA extraction. Therefore, it was recommended that DNA extraction should be performed immediately after IND processing of items. Tsai et al. [77] recommended the use of ethyl acetate based IND formulation to develop LFM on porous surfaces as it did not affect the extraction of DNA, and subsequent STR typing, from deposited LFM on porous surfaces. It was observed that quality and quantity of isolated DNA did not depend on IND processing. Yu and Wallace [78] successfully isolated DNA from IND treated fingerprints deposited on thermal and carbonless papers.

5. Conclusion

1,2-Indanedione (IND) is an effective chemical method to develop latent fingermarks on dry, porous surfaces. It develops pink colored fingerprints which are fluorescent in nature. IND is capable of developing even 11 years old fingerprints and can be used as an alternative to 1,8-diazafluoren-9-one (DFO) [35]. The present technique is simple, rapid, cost effective and non-destructive. Standardized optimization and validation studies should be performed to evaluate the efficiency and reliability of IND method to develop latent fingermarks on difficult surfaces. More research is required to better recognize the reaction mechanism involved and to enhance the sensitivity of this reagent to process aged and degraded latent fingermarks on unusual surfaces.

List of Abbreviations

DFO: 1,8-diazafluoren-9-one; IND: 1,2-Indanedione; IND-Zn: 1,2-Indanedione-Zinc Chloride; JP: Joullie Pink; LFM: Latent fingermarks; NIN: Ninhydrin; ORO: Oil Red O; PD: Physical Developer; PVP: Polyvinylpyrrolidone; TFD-2: Thermal Fingerprint Developer-2

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Conflict of Interest

None to Declare.

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Author's contributions

GSB and SK designed, collected relevant literature and compile the current study in the form of manuscript, SK, GSB and DSB collected the relevant literature and write the manuscript.

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