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Wet SPF: A wet powder suspension for the detection of latent fingermarks on the sticky side of adhesive tape for use in Seychelles

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A R T I C L E I N F O

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A B S T R A C T

WET UCIO is an inexpensive carbon-based powder suspension, reportedly as effective as commercially available formulations for latent fingermark detection on the sticky side of adhesive tapes. However, the surfactant solution used in WET UCIO is not readily accessible outside Europe, limiting its use in Seychelles or other non-European jurisdictions. In this study, the UCIO formulation was modified based on a 'frugal forensic' approach, by replacing the surfactant solution with an in-house sodium dodecyl sulfate solution prepared in 5 % aqueous ethanol. A comparative assessment against Wetwop™ using eight different pressure-sensitive adhesive tapes found that the modified formulation was at least as effective as commercial powder suspension. Modifying this technique under the frugal forensic framework has enhanced its accessibility to other jurisdictions and is recommended for validation in Seychelles.

1. Introduction

Pressure-sensitive adhesive (PSA) tape is a commonly accessible everyday material that is often the subject of forensic analysis. PSA tapes are used in crimes to immobilise or gag victims in kidnapping and homicide cases; seal drug packaging; and construct improvised explosive devices [1–4]. When handled for any purpose, the sticky-side surface of the adhesive tape serves as a substrate for trace evidence such as fingermarks [4–6]. However, the detection of these fingermarks can be challenging due to the intrinsic adhesive nature of PSA tapes. Moreover, the cost of conventionally recommended fingermark detection techniques may limit their accessibility in some jurisdictions.

Powder suspension is an effective and recommended method for developing latent fingermarks on the sticky side of non-porous tapes [7]. This method involves suspending fingerprint powders (black [8], grey [1,9] or white [10,11]) in surfactant solution such as Liquinox [10], Kodak Photoflo [1,9] or Triton™ X-100 [7]. While the exact mechanism is not fully understood, it has been suggested that the powder particles are encapsulated by surfactant micelles, which are then disrupted by certain components of the fingermark residue, causing selective deposition [12]. The destabilisation of the surfactant micelles has been attributed to the eccrine component encapsulated by the water-insoluble constituents [7]. This is based on the observation that powder suspension develops fingermarks on wetted surfaces [13,14] and does not appear to be selective towards sebaceous fingermarks.

The effectiveness of powder suspensions has been reported to depend on several factors including the chemical properties of the PSA tape surface. Adhesive tape generally consists of two primary components: a pressure-sensitive adhesive coated on a backing material. Acrylic and rubber-based natural isoprene or synthetic styrene-butadiene copolymers form the most common adhesives [15,16]. Backings include paper for easy-to-tear tape, polyester for high-strength tapes, and other plastic polymers such as polypropylene, polyethylene, and polyvinyl chloride (PVC) [15]. Modifying additives, such as tackifier resins, plasticisers (e.g. phthalate ester), fillers and pigments (e.g. titanium dioxide, calcium carbonate, barium sulphate, talc, kaolin), may also be incorporated [16,17].

The variation in chemical composition can have a direct impact on the effectiveness of powder suspension. Studies by Bacon et al [18]. using carbon-based suspension powder on various polymer-based substrates, found that titanium dioxide pigments in polymer substrates cause surface-wide background staining. This was not observed for similar polymer substrates without titanium dioxide pigments or where the pigments were 30 nm below the surface. Other factors include the surfactant critical micelle concentration (CMC), a concentration above which surfactant micelle structures spontaneously form [19], and the

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type and size of the powders. Studies have shown that formulations containing Triton™ X-100 surfactant below the CMC result in relatively higher background staining [12]. Another study on powder particle size reported superior efficacy with iron oxide (II/III) powders exhibiting high sub-micrometre particle population [20].

In recent years, several pre-mixed commercial proprietary powder suspension formulations have become available [21–23]. Black powder suspension is either carbon or iron oxide-based, with the former being the recommended method for treating light-coloured adhesive sides of non-porous tape [7]. However, its operational use may be limited in small laboratories with restricted budgets due to its high cost (for example Wetwop™ costs $340 USD per litre). Another consideration when using a pre-mixed product is the general lack of control over formulation quality and shelf-life [24]. This has led to interest in developing cheaper in-house alternatives.

A recent example is the development of Wet UCIO powder suspension [25], consisting of carbon black powder (Sirchie Silk Black) mixed with a commercial surfactant solution (Gran Velada). The commercial Gran Velada surfactant solution contains 27 % w/v of sodium dodecyl sulfate (SDS) [25], an anionic surfactant consisting of a hydrophobic alkyl tail of 12 carbon atoms attached to a hydrophilic sulfate group. This formulation has been reported to be more effective than commercial Wetwop™ on eight types of adhesive tapes [25], while only costing c.a $64 USD per litre (at least five times cheaper than Wetwop™). However, the Gran Velada surfactant solution is not readily accessible outside Europe [26], limiting its use in Seychelles or other non-European jurisdictions.

SDS is a low-cost and common surfactant used in various detergent, cosmetic, pharmaceutical and food products [27–30]. Given the accessibility, cost-effectiveness and low toxicity [31], lab-grade SDS presents a sustainable alternative to the Gran Velada surfactant solution. Laboratory grade SDS is available in different forms, either aqueous solutions of concentration 10 % or 20 % w/v, or in powder form to produce in-house surfactant solution. The latter offers better transportation, storage, and quality control. Additionally, preparing fresh or small-volume stock solutions as and when required provides better shelf-life and reduces wastage, which aligns with a frugal forensic approach.

This study aims to enhance the accessibility of the WET UCIO powder suspension by exploring readily available SDS salts to produce an in-house surfactant solution as a substitute for the Gran Velada solution. The study involves characterising pressure-sensitive tapes to assess and consider the surface's chemical composition and possible impact on modifying the WET UCIO formulation, followed by a comparative assessment against a commercial formulation currently used in Seychelles.

2. Materials and methods

The experiments were carried out in three stages. The formulation was first modified and then compared with WET UCIO in a Phase 1 type study in line with the International Fingerprint Research Group (IFRG) guidelines [32]. The modified method was then compared to the commercial pre-mixed formulation Wetwop™ using a more comprehensive IFRG Phase 2 type study.

2.1. Substrates

Twelve PSA tapes of various brands and types were purchased in new condition for this study (Table 1). Investigation primarily made use of six tapes (#1 to #6), with additional insulating tapes (#7 to #12) subsequently purchased to investigate the background staining observed on this type of tape. Before sample preparation, the length circumference of each tape was discarded to ensure a clean surface for IR analysis and fingermark deposition.

Table 1
Details of tapes used in this study.

Sample Code	Tape Type	Brand	Colour	Source
Tape #1	Packaging	Scotch 3M	Transparent	Officeworks
Tape #2	Packaging	Scotch 3M	Transparent	Officeworks
Tape #3	Packaging	Bear	Brown	Bunnings
Tape #4	Duct Tape	Paint Partner	Silver	Bunnings
Tape #5	Masking	PPS	White	Officeworks
Tape #6	Insulating	Nitto	Yellow	Bunnings
Tape #7	Insulating	Click	Red	Bunnings
Tape #8	Insulating	Click	Blue	Bunnings
Tape #9	Insulating	Click	Black	Bunnings
Tape #10	Insulating	Click	White	Bunnings
Tape #11	Insulating	Deta	Yellow	Bunnings
Tape #12	Insulating	Nitto	White	Bunnings

2.2. ATR-FTIR tape characterisation

PSA tapes were analysed using a Thermo Scientific Nicolet iS50 FTIR spectrophotometer with a single-bounce ATR diamond crystal. Spectra were obtained in absorbance mode over a range of 4000 – 400 cm^{-1} at 4 cm^{-1} resolution, with 64 accumulated scans. For each tape, a ca. 5 cm strip was cut and placed over the crystal, using the pressure arm to maintain a consistent contact pressure. The backing and the adhesive side were analysed using separate strips with replicate measurements taken at three locations for each. The crystal was cleaned with ethanol and a new background scan collected between different tape samples. Spectra were ATR corrected using Omnic software (Version 9), with the replicate spectra then averaged and exported as.csv files for analysis.

2.3. Fingermark collection

Fingermarks were collected ten donors (four females and six males aged between 22 and 60). For the initial formulation modification and simple comparison with WET UCIO, fingermarks were collected from a subset of the pool of donors and samples were allowed to age under ambient laboratory conditions for at least 24 hours before processing. Table 2 provides an overview of the number of donors and tapes used for each experiment.

Tape samples of approximately 20 cm strips were cut, and acetate backing tabs were placed at each end on the adhesive side for labelling and handling purposes. The tape strips were secured with the adhesive side facing up on a corflute sheet containing a background grid to indicate position to deposit fingermarks. Each tape sample consisted of a set of five fingermark depositions. Two samples of the same tape were secured side by side for split fingermark deposition as illustrated in Fig. 1.

Fingermark donors were instructed to lightly rub their hands together and provide natural fingermarks by lightly pressing the finger on the substrate surface for ~5 seconds. Care was taken to ensure that the donor had not washed their hands, eaten, or come into contact with

Table 2
Details of the number of donors and tapes used in each experiment.

Experiment stage	Experiment type	Number of Donors	Tapes used
A	Formulation modification	5	#1, #2
	Wet SPF formulation	3	#1, #2
	Insulating tape background staining	5	#6, #7, #8, #9, #10
B	Simple comparison Wet SPF to Wet UCIO	5	#2, #3, #6
	Insulating tape background staining	5	#6, #7, #8, #9, #10
C	Comparative assessment Wet SPF to Wetwop	10	#2, #3, #4, #5, #6, #10, #11, #12
	Sensitivity test	5	#1, #4, #7

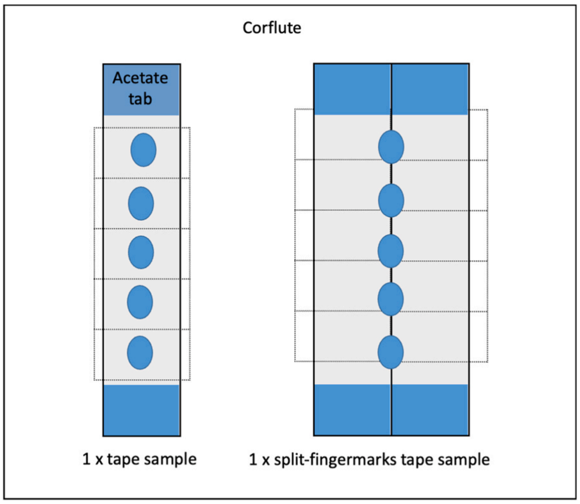

Fig. 1. Schematic of latent fingermark deposition on tape samples.

chemicals in the 30 minutes prior to sample collection to reduce contamination and ensure a natural build-up of surface secretions. Multiple samples collected from the same fingermark donor were collected with at least 30 minutes intervals between deposition of each sample to allow secretions to replenish on donors' fingertips.

2.4. Powder suspension preparation and sample development

Commercial powder suspension products Wetwop™ Black (Lightning Powder Company) and Wet Powder™ Black (Kjell Carlsson Innovation) were manually agitated for 10 seconds before use. A working solution of approximately 10 mL was poured into a clean beaker. In this study, Wetwop™ Black and Wet Powder Black™ are referred to as Wetwop and Wet Powder unless otherwise stated.

The Wet UCIO formulation was prepared as outlined by Claveria et al. [25]. 1.5 g of carbon black powder (Sirchie) was mixed with 10 mL of 27 % w/v SDS (Gran Velada) to make a suspension similar in texture to thin paint. Modified WET UCIO formulations were prepared by substituting the Gran Velada solution with in-house surfactant solutions of various SDS concentrations. These were prepared from SDS salt (Laboratory grade, Chem Supply), absolute ethanol (Analytical grade, Scharlab), polyethylene-400 (Laboratory grade, Chem Supply) and deionised water using volumetric glassware. The composition of the various modified Wet UCIO powder suspension formulations and the approximate CMC of the in-house surfactant solutions utilised in this study are specified in Table 3.

All powder suspensions were prepared fresh and their application followed the same methodology. A separate clean brush was used for each powder suspension formulation to paint the suspension onto the sticky side of adhesive tapes and left for 10–15 seconds. The tapes were rinsed with cold tap water and then air dried.

Table 3
Composition and approximate CMC of in-house surfactant solution used in this study. The CMC of SDS was taken to be 8.2 mM. [33].

Designation	Surfactant solution composition	SDS CMC (approx.)
1 % SDS	1 g SDS in 100 mL deionised water	4 x CMC
5 % SDS	5 g SDS in 100 mL deionised water	20 x CMC
10 % SDS	10 g SDS in 100 mL deionised water	40 x CMC
27 % SDS	27 g SDS in 5 mL ethanol and 95 mL deionised water	100 x CMC
15 % SDS (Wet SPF)	15 g SDS in 5 mL ethanol and 95 mL deionised water	60 x CMC

2.5. Formulation modification

Experiments were conducted to explore the effectiveness of modified WET UCIO powder suspension prepared with SDS concentrations of 1 %, 5 %, and 10 % w/v. Due to limited Gran Velada SDS surfactant solution available for this study, an in-house modified Wet UCIO powder suspension produced from 27 % SDS was used for the preliminary comparison. To achieve 27 % w/v SDS concentration, the surfactant was dissolved in 5 % v/v ethanol/deionised water mixture.

Each donor deposited four sets (one for each formulation) of single fingermarks on each type of tape (acrylic and rubber-based adhesive). Additionally, a modified Wet UCIO formulation produced from 15 % w/v SDS (designated "Wet SPF") was compared with the 27 % w/v SDS formulation, using the same tapes as above. Each donor deposited two sets of split five-depletion series fingermarks on each tape to provide an initial insight into the sensitivity of this formulation.

2.6. Simple comparison to WET UCIO

The Wet SPF formulation was subsequently compared to WET UCIO in line with Phase 1 of the IFRG guidelines. Each donor deposited two sets (one for each formulation) of five-depletion series fingermarks on each of the three tapes: packaging, duct and insulating tape. Background staining observed on insulating tape was investigated using three different powder suspensions (Wet SPF, WET UCIO and Wet Powder) on five insulating tapes. Each donor deposited three sets (one for each formulation) of a single fingermark on each tape.

2.7. Comparative assessment to Wetwop

An assessment was made of the relative performance of Wet SPF powder suspension with the commercial Wetwop, which is the current operational technique in Seychelles. The assessment was carried out on eight adhesive tapes for two ageing periods (one week and four weeks) under ambient laboratory conditions in line with Phase 2 of the IFRG guidelines [32]. Each donor deposited two sets (one for each ageing period) of single split fingermarks on each tape. To assess sensitivity, ten depletion series of split fingermarks were collected from each donor on each of the three tapes. The samples were aged for one week under ambient laboratory conditions before development.

2.8. Sample visualisation, and grading

Visual examination and photography of fingermarks were conducted under reflected white light conditions except for black insulating tape, where a Polilight PL500 (Rofin, Australia) with an excitation wavelength of 505 nm and OG Schott 550 nm barrier filter was used. Samples were photographed using a Nikon D300 camera attached to a Firenze Mini Repro tripod and connected to a computer using Nikon Camera Control Pro Version 2.0.0. Sample images were graded by an independent assessor using the Home Office Centre for Applied Science and Technology (CAST) assessment scale [33], as described in Table 4.

2.9. Statistical analysis [34]

Statistical analysis software R version 4.3.0 was utilised to assess whether there was a significant difference in the fingermark grades developed between the two powder suspension formulations in the comparative assessment. The Mann-Whitney U test and chi-squared test were used to assess the overall performance (n= 320) and sensitivity (n= 300) between Wet SPF and Wetwop. Additionally, a difference in proportion test was also performed on both data sets to assess whether the proportion of grade 3 s and 4 s (useful fingermarks) of one treatment differs from the other. All statistical tests were carried out at the 95 % confidence level ($p < 0.05$).

Table 4
Assessment scale [33] and grade classification used in this study.

Grade	Friction ridge detail developed	Contrast of ridge detail	Classification
0	No evidence of mark	No contrast	No evidence of mark
1	Weak development; evidence of contact but no ridge detail	Poor contrast	Detected, but not suitable for comparison
2	Limited development, ridge details present but not likely to be used for identification purposes	Moderate contrast	Detected, but not suitable for comparison
3	Strong development more than 2/3 of fingermark continuous ridges	Good contrast	Suitable for comparison (useful fingermarks)
4	Very strong development: full ridge details	Very good contrast	Suitable for comparison (useful fingermarks)

3. Results and discussion

3.1. Tape characterisation

The chemical composition of PSA tapes may affect powder suspension performance; hence characterisation of the tapes was carried out. The IR spectra obtained allowed the backing and adhesive of the 12 tapes used in this study to be grouped based on the main polymer present. The backing was categorised into four groups: polypropylene, polyethylene, cellulose acetate and PVC; whereas the adhesive was differentiated into two groups, namely acrylic and synthetic rubber-based polymer (Table 5). All spectra and a summary of key diagnostic peaks are provided in Supplementary Materials A.

Notably, visual examination of the spectra showed that the insulating tapes displayed high similarities with only subtle variations in the fingerprint region, despite originating from three distinct manufacturers. As shown in Fig. 2. the Nitto tapes (#6 and #12) could be distinguished from the other brands. These differences in chemical composition were attributed to variation in pigments such carbonates and titanium dioxide [35–37], which may cause variation in the effectiveness of powder suspension across the different insulating tapes.

Table 5
Classification of adhesive and backing composition based on IR analysis of the main polymer type.

Sample Code	Tape Type	Brand	Colour	Adhesive Composition	Backing Composition
Tape #1	Packaging	Scotch 3 M	Transparent	Acrylic	Polypropylene
Tape #2	Packaging	Scotch 3 M	Transparent	Rubber	Polypropylene
Tape #3	Packaging	Bear	Brown	Acrylic	Polypropylene
Tape #4	Duct Tape	Paint Partner	Silver	Rubber	Polyethylene
Tape #5	Masking	PPS	White	Rubber	Cellulose
Tape #6	Insulating	Nitto	Yellow	Rubber	PVC
Tape #7	Insulating	Click	Red	Rubber	PVC
Tape #8	Insulating	Click	Blue	Rubber	PVC
Tape #9	Insulating	Click	Black	Rubber	PVC
Tape #10	Insulating	Click	White	Rubber	PVC
Tape #11	Insulating	Deta	Yellow	Rubber	PVC
Tape #12	Insulating	Nitto	White	Rubber	PVC

3.2. Preliminary considerations

SDS is relatively hydrophilic with a water solubility for commercial salts ranging between 130 and 150 g/L at 20 °C [31,38], and a generally accepted CMC of 8.1 mM at 25 °C [39–42]. To obtain a high SDS surfactant concentration similar to that of Gran Velada solution (27 % w/v), organic solvents (e.g ethanol, glycols or glycol ethers) are typically used as additives in the composition [43]. Preparation of in-house 27 % w/v SDS surfactant (comparable surfactant concentration to the Gran Velada solution) in water formed crystalline structures a day after preparation. This indicates that the Gran Velada surfactant solution likely contains an additive to keep the high concentration of SDS dissolved, although this was not stated on the material and safety data sheet [44]. Investigating in-house SDS surfactant solution with concentrations below the water solubility or the use of additives was therefore of interest.

3.3. Formulation modification

The results for powder suspensions prepared from in-house surfactant solution with different SDS concentrations are presented in Fig. 3. Formulations containing 5 % (~20 x CMC) SDS and above were effective in developing fingermarks with grades 3 and 4 (useful fingermarks). In contrast, no useful fingermarks were developed with powder suspension prepared from 1 % SDS (~ 4 x CMC). The variation in fingermark quality with SDS concentration was observable when examining the degree of powder deposition, as shown in Fig. 3b. The powder suspension with 1 % SDS exhibited low contrast due to high background staining and minimal powder deposition on the fingermarks. Increasing the SDS concentration reversed the trend, with the 27 % SDS powder suspension resulting in high deposition on the fingermarks and a relatively clean background. This pattern was observed on both acrylic and rubber-based tapes but was more noticeable on the former.

The findings underline the critical role of surfactant concentration in the effectiveness of powder suspension. The result is consistent with a previous study by Downham et al. [12], which showed the need for surfactant concentration to be above the CMC (2 x CMC) when using Triton X-100 surfactant in an iron oxide powder suspension to prevent indiscriminate staining. This study indicates that a surfactant concentration above 4 x CMC of SDS is necessary for carbon-based powder suspension. Compared to the non-ionic Triton X-100, the ionic nature of SDS surfactant likely increases its interaction with the background surface, resulting in a greater disturbance of the surfactant micelles, hence necessitating a higher concentration.

Whilst 27 % SDS formulation developed the highest quality fingermarks, the difference with the 10 % SDS formulation was minor. However, the latter showed slightly higher background development indicating that a SDS concentration above 10 % is required for optimal quality of developed marks. Moreover, 27 g of SDS to produce 100 mL of surfactant solution was deemed a sizeable amount given the low density of SDS [38]. Reducing the surfactant concentration would be more cost-effective and relatively less likely to precipitate over time. To adhere to the principles of frugal forensics, which aim to maintain quality while reducing costs, a 15 % w/v surfactant solution containing a mixture of 5 % v/v ethanol and deionised water (Wet SPF) was investigated. This solution was chosen as a middle ground between cost and quality. Ethanol, a readily available laboratory reagent, was used as an additive to avoid precipitation of SDS. Wet SPF was found to be equally effective and sensitive in developing fingermarks as the formulation containing 27 % SDS, on both acrylic- and rubber-based PSA tapes as shown in Fig. 4. Therefore, the Wet SPF formulation was brought forward for further investigation.

3.4. Simple comparison to WET UCIO

Comparison of Wet SPF to Wet UCIO (Fig. 5a) shows that both formulations are highly effective on packaging and duct tape, with all

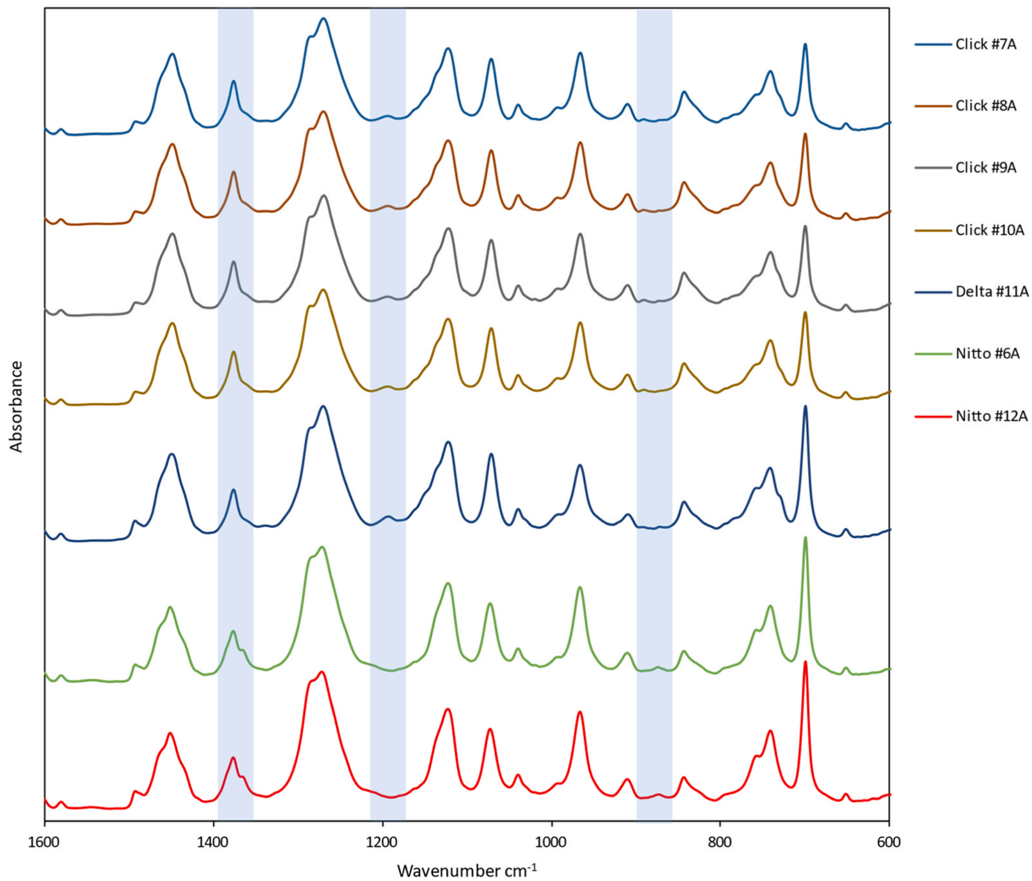

Fig. 2. Comparison of infrared spectra of different insulating tape synthetic rubber adhesive. The main differences are highlighted (blue shaded regions).

fingermarks graded as useful, except for the Nitto insulating tape. Overall, the percentage of useful fingermarks developed was 68 % for Wet SPF and 60 % for WET UCIO, lower than the 86.5 % effectiveness reported by Claveria et al [25]. using WET UCIO on five rubber-based adhesives. The reduced effectiveness was attributed to the indiscriminate background staining observed on insulating tape #6 (Fig. 5b). This is likely a result of the variations in substrate chemical composition, due to pigments such as titanium dioxide in the adhesive tape as indicated by the visual examination of the IR spectra. Pigments such as titanium dioxide have been reported to cause widespread background staining with carbon-based powder suspension [18].

Another observation was that the powder deposition was more intense with Wet SPF than with WET UCIO formulation (Fig. 5b). This may explain why 24 % of the fingermarks developed with WET UCIO on insulating tape #6 were undetected (grade 0). In contrast, all fingermarks were detected with Wet SPF formulation, but a high percentage were graded as not useful, due to low contrast caused by background staining. Although subtle, the differential powder deposition on fingermarks was also observed on packaging tape #2 and duct tape #4 with Wet SPF formulation exhibiting darker fingermarks compared to WET UCIO. One possible cause is the difference in SDS concentration. Wet SPF has a concentration of 15 % w/v while WET UCIO has 27 % w/v. During these experiments, no significant differences were observed between the two SDS concentrations, indicating that other factors such as the presence of additives may be influencing the results. The use of organic solvent has been shown to influence the micellisation process and wettability properties of surfactant [42,43,45,46]. However, further investigation into the use of PEG-400 as an alternative additive to ethanol and variation in their concentration gave comparable effectiveness (Supplementary Materials B). This indicates that the two additives appeared to have minimal impact on the effectiveness of Wet SPF formulation, although this does not refute the possibility that the additive used in Gran Velada surfactant solution may cause a minor reduction in powder deposition.

Investigation into the five insulating tapes revealed that the background staining was specific to Nitto tape #6, with all formulations exhibiting similar results. An example of the result on other insulating tape is shown in (Fig. 6). The IR analysis showed that all insulating tapes were of PVC backing and rubber-based adhesive, but the Nitto tapes showed slight differences in chemical composition compared to the other brands. This strongly suggests that background staining is substrate related and more likely due to additives in the adhesive as discussed above.

Interestingly, the insulating tape #9 used in this study was black-coloured, which is generally processed with white powder suspension for better contrast. However, in this study, the carbon-black-based powder was used, and visualisation was achieved by exploiting the difference in luminescence [47] between the treated fingermark and tape surfaces (Fig. 6b). Specifically, the treated black-coloured tape was examined using a Polilight under different excitation wavelengths and filters to obtain the best viewing conditions. The combination of 505 nm excitation and 550 nm filter was found to be optimum, as the visualised marks closely resemble black and white fingermarks, which are generally preferred by practitioners [47]. The result indicates that carbon-based powder suspension may be used for both light and dark tapes, which offers a cheaper alternative to commercial white powder suspensions. However, further investigation is required on a larger subset of samples of various types of dark-coloured tapes. Moreover, it is recognised that a Polilight may not be readily available in all jurisdictions - although it is currently being used in Seychelles. Therefore, future research can explore the possibility of implementing low-cost LED-based light sources.

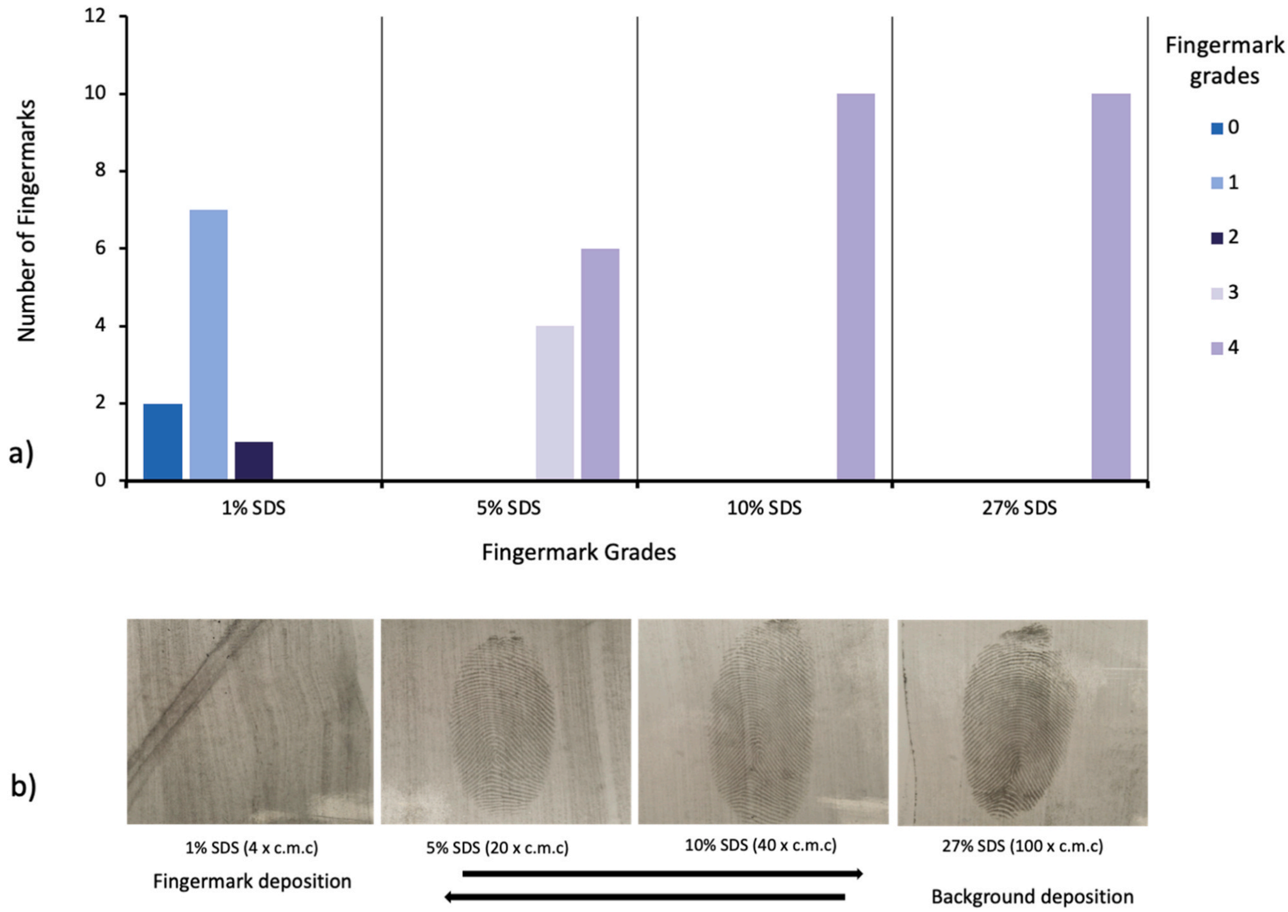

Fig. 3. Comparison of (a) the number and grades of fingermarks developed (b) the degree of powder deposition on fingermarks and background after treatment with modified WET UCIO powder suspensions prepared with 1 %, 5 %, 10 % and 27 % w/v SDS surfactant solution.

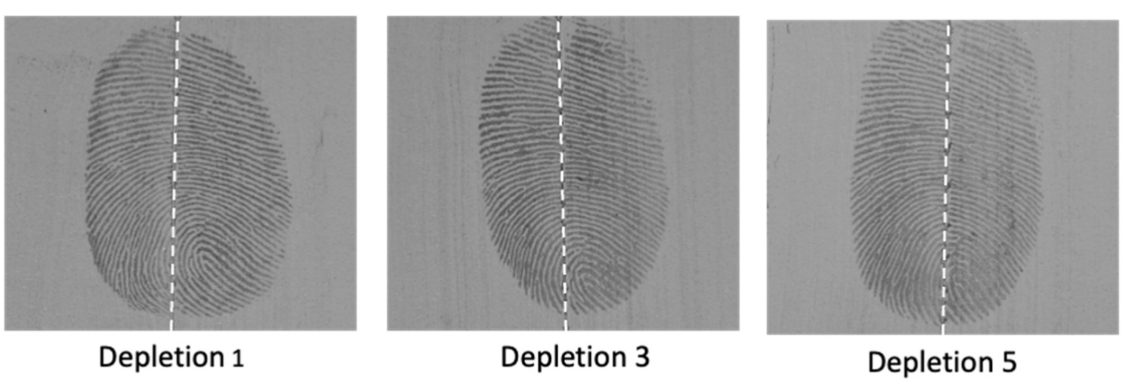

Fig. 4. Comparable performance and sensitivity of Wet SPF formulation (left) and 27 % SDS-modified WET UCIO formulation (right) in developing fingermarks on rubber-based adhesive tape.

3.5. Comparative assessment to Wetwop

The comparative assessment of Wet SPF and Wetwop powder suspension in developing one-week- and four-week-old fingermarks deposited on eight adhesive tapes by a range of 10 donors is summarised in Fig. 7. In total, 320 split fingermarks were graded to provide an insight of the overall performance with Wet SPF formulation developing 68 % of useful fingermarks and Wetwop 61 %. The result clearly shows the comparative effectiveness of Wet SPF to the commercial Wetwop powder suspension on both acrylic and rubber-based PSA tapes tested.

The results for one week and four week samples are presented in Fig. 8. Both formulations appeared to be more effective on older fingermarks. The effectiveness of powder suspension on older fingermarks has been suggested to be due to the loss of the water-soluble eccrine component over time, exposing and reducing the interaction distance between the eccrine components encapsulated within the non-water soluble constituents and particles of powder suspension [7]. The result demonstrates the applicability of Wet SPF on aged fingermarks that are likely to be encountered in casework.

In terms of substrates, both formulations exhibited high effectiveness in developing fingermarks on acrylic and rubber-based PSA tapes, with exception of Nitto rubber-based insulating tapes #6 and #12, and

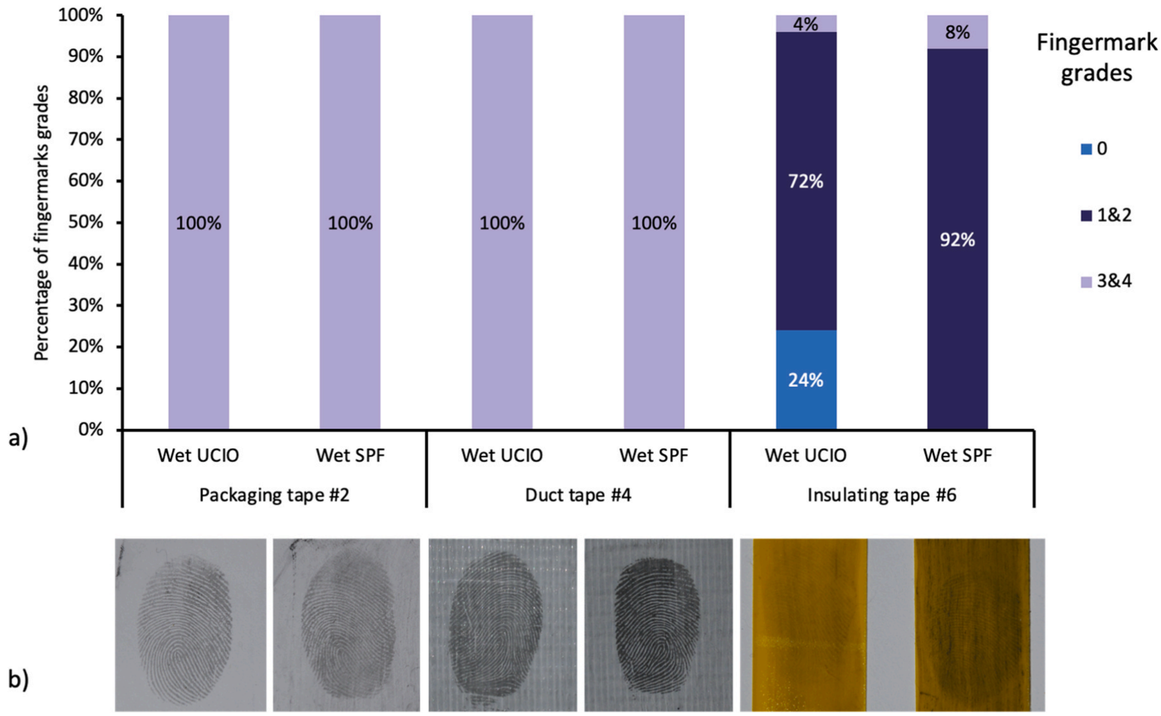

Fig. 5. Comparison of (a) percentage of fingermarks graded (3&4), (1&2), and (0) out of 150 fingermarks (b) the degree of powder deposition on fingermarks and background after treatment with WET UCIO and Wet SPF powder suspensions on packaging tape, duct tape and insulating tape.

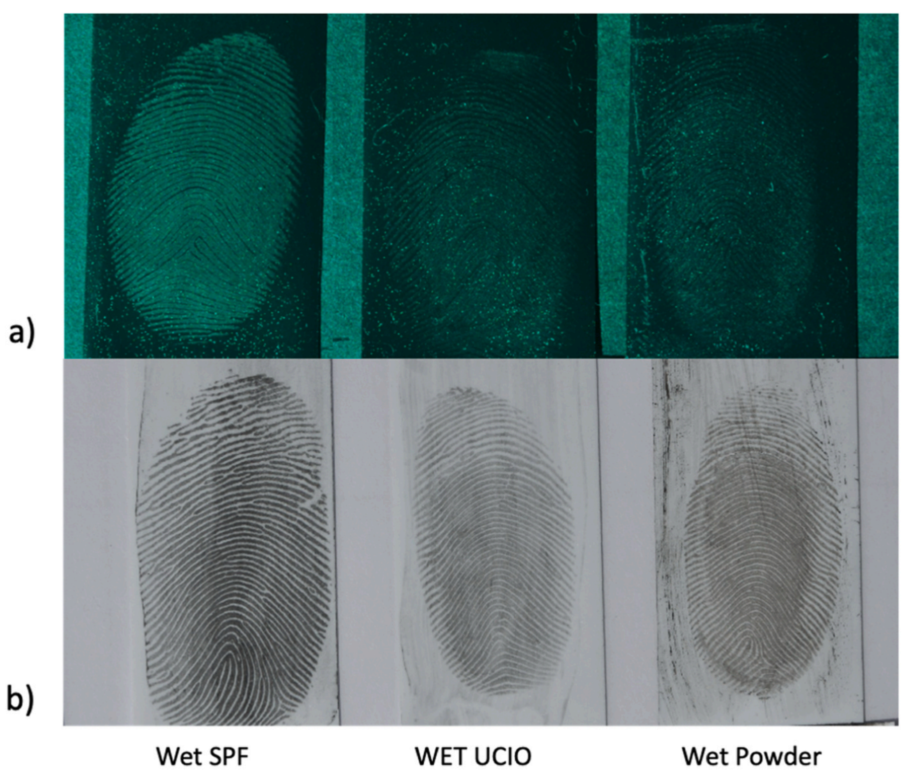

Fig. 6. Fingermark ridge details and contrast after treatment with Wet SPF, WET UCIO and Wet Powder on (a) Click black insulating tape #9 under 505 nm excitation and 550 nm filter. (b) Click white insulating tape #10 under white light.

rubber-based masking tape #5 (Table 6).

As expected, Nitto insulating tapes #6 and #12 exhibited background staining, resulting in poor effectiveness. In contrast, both formulations were highly effective in developing useful fingermarks on insulating tapes #10 and #11, which were of similar colour but from a different manufacturer. These results reinforced the suggestion that this is due to the chemical composition of the Nitto adhesive PSA tapes. Excluding the Nitto insulating tapes, Wet SPF and Wetwop percentage effectiveness increases to 89 % and 81 % respectively, closer to the reported 92 % effectiveness of the Wet UCIO method [25].

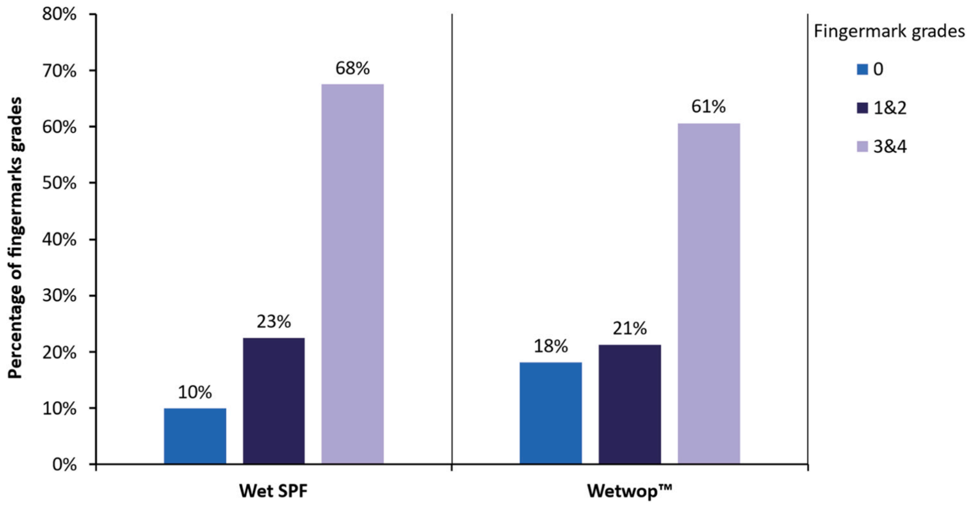

Fig. 7. Percentage of fingermarks graded (3&4), (1&2), and (0) out of 320 fingermarks developed with Wet SPF and Wetwop on eight different types of tape.

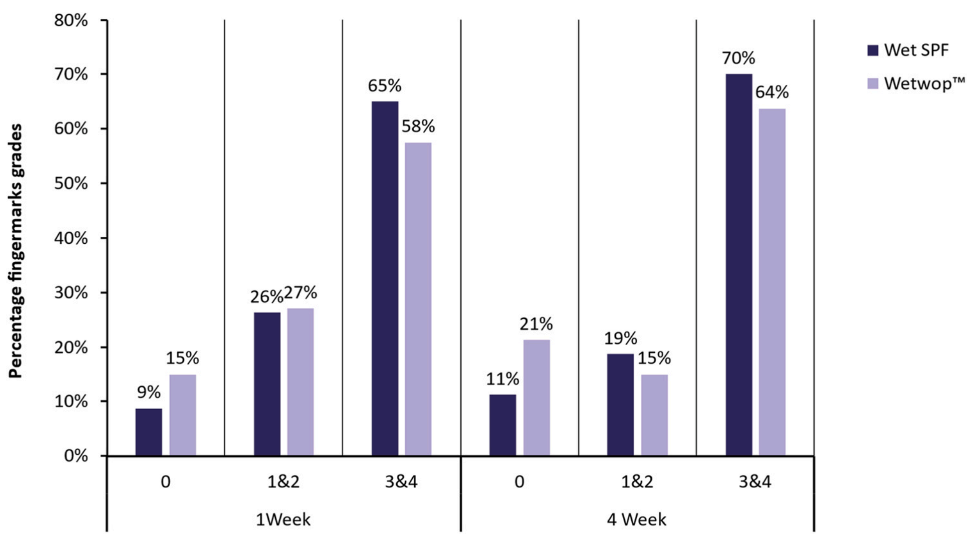

Fig. 8. Percentage of fingermarks graded (3&4), (1&2), and (0) out of 320 fingermarks developed with Wet SPF and Wetwop on eight different types of tape aged for one week and four weeks.

Table 6
Percentage of fingermarks graded 3 and 4 on each of the eight types of adhesive tape.

Sample Code	Tape type and colour	Brand	Adhesive Composition	Wet SPF	Wetwop
Tape #2	Packaging (Transparent)	Scotch 3 M	Rubber	100 %	85 %
Tape #3	Packaging (Transparent)	Bear	Acrylic	100 %	100 %
Tape #4	Duct Tape (Silver)	Paint Partner	Rubber	100 %	90 %
Tape #5	Masking (White)	PPS	Rubber	40 %	25 %
Tape #6	Insulating (Yellow)	Nitto	Rubber	5 %	0 %
Tape #10	Insulating (White)	Click	Rubber	100 %	95 %
Tape #11	Insulating (Yellow)	Deta	Rubber	95 %	90 %
Tape #12	Insulating (White)	Nitto	Rubber	0 %	0 %

On the rubber-based masking tape #5, Wet SPF and Wetwop were found to be 40 % and 25 % effective, respectively. A similar effectiveness of 37.5 % was reported for rubber-based masking tape with WET UCIO powder suspension [25]. Examination of the developed fingermarks showed that despite a relatively clean background, poor contrast was observed since the interspace between ridges was partly stained (Fig. 9). This is likely due to the semi-porous cellulose backing, which could allow some of the suspension to diffuse into and stain the cellulose matrix, reducing the overall contrast with the developed marks.

A total of 300 split fingermarks comprising up to the 10th depletion were processed to assess the sensitivity of Wet SPF compared to Wetwop. Fig. 10 shows the sensitivity results with 1st to 5th depletions and 6th to 10th depletions grouped together. The result indicates superior sensitivity, particularly for the 6th to 10th depletion series. As discussed earlier, this is due to higher powder deposition on fingermarks exhibited by Wet SPF resulting in better effectiveness in developing weaker fingermarks.

A Mann-Whitney U test, chi-squared test and difference in proportion test performed on the overall performance data showed no significant difference in the fingermark grades ($p = 0.051$), distribution of frequencies ($p = 0.057$), or proportion of grades 3 s and 4 s ($p = 0.2$)

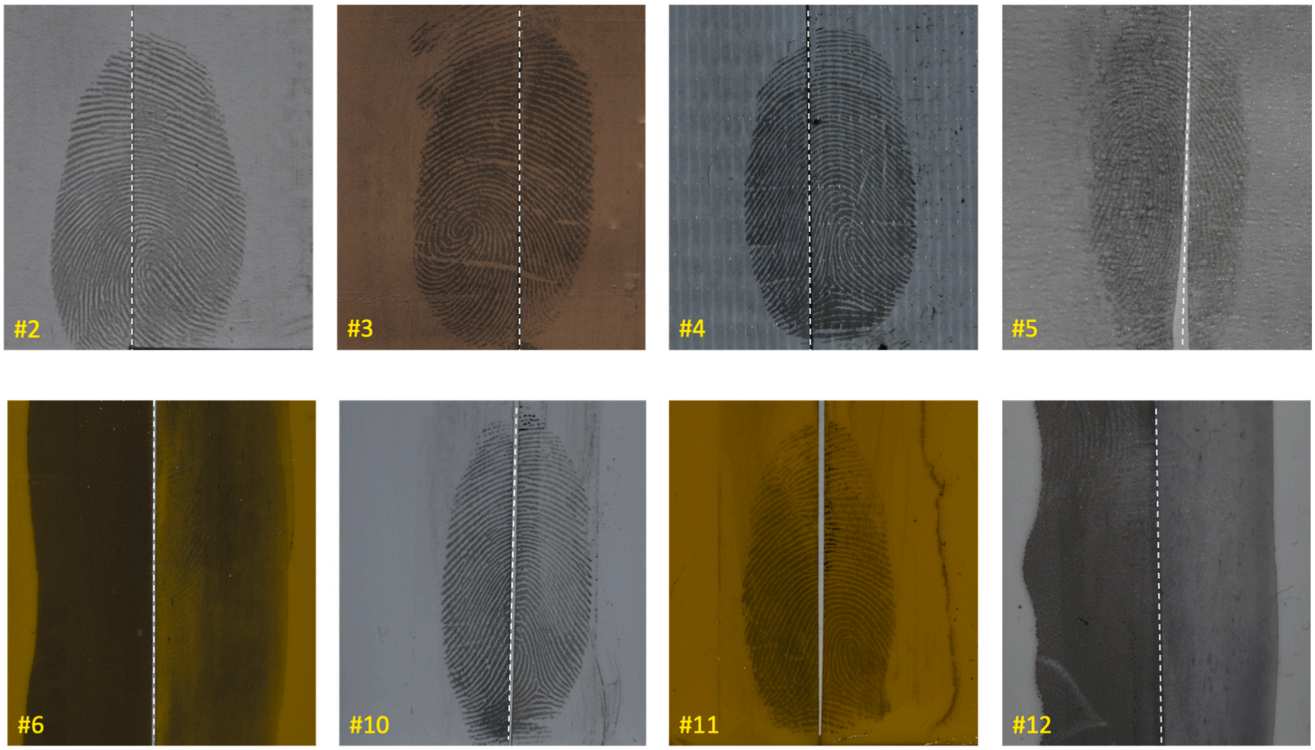

Fig. 9. Examples of fingermark developed with Wet SPF (left) and Wetwop (right) on eight pressure sensitives tapes; #2 Scotch 3 M clear packaging tape, #3 Scotch 3 M brown packaging tape, #4 Paint Partner silver duct tape, #5 PPS white masking tape, #6 Nitto yellow insulating tape, #10 Click white insulating tape, #11 Delta yellow insulating tape, #12 Nitto white insulating tape.

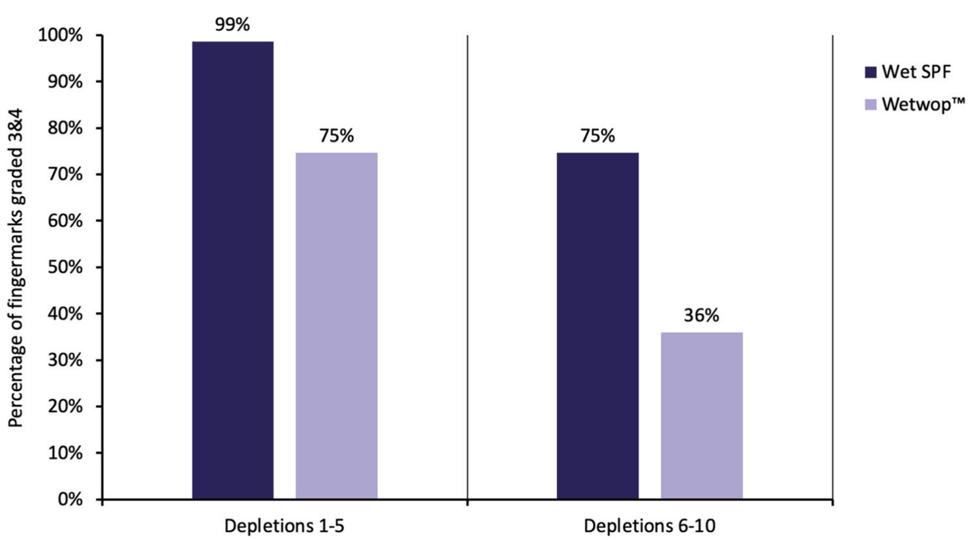

Fig. 10. Percentage of fingermarks graded 3 and 4 out of 300 fingermark halves developed with Wet SPF and Wetwop on three different types of tape grouped into depletion series 1–5 and 6–10.

between Wet SPF and Wetwop. On the sensitivity data, all three tests revealed significant differences ($p = 0.2 \times 10^{-8}$, 0.7×10^{-8}, 0.2×10^{-8} respectively). The statistical results reinforce the observation that the performance of Wet SPF is generally comparable in performance and shows better sensitivity to commercial Wetwop black powder suspension. The R code and results of all statistical analysis are provided in Supplementary Materials C.

Regarding reagent stability, Wet SPF prepared with SDS solution over six months old was found to be as effective as suspension powder prepared with fresh SDS solution. It has also been reported that aqueous SDS solution can remain stable for up to three years [48]. Although further studies are required to test the shelf life of the Wet SPF suspension powder mixtures, preparing the formulation fresh as and when needed is recommended to avoid wastage, given its ease of preparation.

4. Conclusion

Based on the frugal forensic approach, this study successfully modified the recently published WET UCIO powder formulation by replacing the inaccessible surfactant solution with an in-house sodium dodecyl sulphate surfactant solution.

The Wet SPF powder suspension containing 15 % SDS in a 5 %

ethanol/water mixture has been shown to be as effective as the commercial Wetwop powder suspension on eight different tapes using ten donors. Other benefits include an inexpensive formulation and readily available surfactant, accessible from multiple suppliers. In respect to remote-location jurisdictions, the use of salts compared to commercial solution surfactants allows for easy transportation, storage and better control of quality and shelf-life.

The use of Wet SPF combined with a forensic light source was found to be effective for visualising fingermarks on the challenging surface of dark-coloured adhesive tapes. Further studies on the comparative assessment with commercial white powder suspension are suggested, as this may allow the use of a single formulation suited to both light- and dark-coloured substrates.

Based on this successful demonstration in line with IFRG Phase 2 studies, the Wet SPF method is recommended for validation as an operational technique in Seychelles for developing latent fingermarks on adhesive tapes. The recommended formulation is as follows:

1.5 g Sirchie Silk Black fingerprint powder
10 mL of 15 % sodium dodecyl sulfate solution
15 % sodium dodecyl sulfate solution is as follows –
15 g of sodium dodecyl sulfate
100 mL of 5 % ethanol/deionised water mixture.

CRediT authorship contribution statement

Jemmy T. Bouzin: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Georgina Sauzier:** Writing – review & editing, Supervision, Conceptualization. **Simon W. Lewis:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.forsciint.2024.112044.

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