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Forensic Applications of IR Spectral Data at Macro and Micro Levels: A Study on Plastic Packages

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Forensic Applications of IR Spectral Data at Macro and Micro Levels: A Study on Plastic Packages

ABSTRACT Plastic packaging is one of the most commonly used methods among illicit heroin packers. Distribution starting from the manufacturer to the end users may involve replacement of larger plastic bags with smaller packets as the mass of heroin is divided into smaller portions for street sales. Conventionally, polymeric compositions of these materials are often used qualitatively to distinguish between the types of plastic packets the drug distributors tend to use. In addition, spectral differences when statistically manipulated can also help further differentiate the plastic packets of a particular type. In this study, the IR technique has identified five polymeric types at the macro level from 311 heroin cases involving the use of plastic packages. The most frequently encountered Type 1-Polypropylene-based plastic packets were further distinguished at the micro level by principal component analysis after IR data pretreatment. Possible forensic interpretations about the packers involved in heroin cases were also outlined based on the findings obtained at the two levels. Using IR technique alone is the preliminary step in forensic profiling. Further analysis of other aspects associated with these packages is required for more precise intelligence work.

KEYWORDS forensic, heroin, IR, plastic, spectral differences

INTRODUCTION

Illicit heroin remains the leading drug of abuse in Malaysia. The local law enforcement authorities have not ceased to counteract this controlled substance based on its record seizures over the last decade. Aside from the routine chemical analysis aimed at providing laboratory evidence for prosecution, forensic intelligence has come into play to derive new knowledge by gathering, collating, analyzing, interpreting, and distributing all relevant data obtained from the law enforcement bodies and laboratory findings in the zeal of locating illicit drug manufacturers as the ultimate goal. In search of these data from the heroin seizures, most efforts have been channeled to chemical analysis of heroin substance using advanced instrumentation.[1–4] However, the role of the plastic packages is often overlooked. This source when effectively employed will add invaluable
information to the index of existing knowledge about its possible manufacturing plants.

A database of plastic packaging such as plastic bags and films was formerly set up by the authorities in Australia, based on the evidence that the package profiles were able to help trace the source of illicit drugs.\[5\] Research on plastic packages proved some degree of discrimination power in segregating shopping plastic bags used by traffickers.\[6\] Inspection on the general appearance of plastic folding and wrapping also helps to establish initial identification. For example, if plastic packages similar to the “square like” or “amorphic” packages described by Zamir et al.\[7\] are seized, they are believed to have come from countries other than Malaysia because this mode of packing is uncommon in Malaysia. A degree of subjectivity may arise from this visual inspection, and thus instruments become indispensable to enhance the confidence level in drawing a conclusion. A multitude of methods for analyzing plastic polymers have been described.\[8–11\] In the forensic context, ultraviolet spectrophotometer (UV), Fourier transform infrared spectroscopy (FT-IR), differential scanning calorimetry (DSC), and wide-angle X-ray diffraction (WADX) are certainly the methods of choice for relatively quick analysis of polymeric films.\[5–6,12\] Among these techniques, FT-IR is particularly of utility because it does not show significant variations in the results after the same films are subjected to different storage conditions.\[13\] This excellent strength makes FT-IR a robust method in most analyses in addition to its rapidity and less sample preparation. More effectively, FT-IR spectra coupled with striation marks and other physical characteristics found on the plastic films are potentially useful in estimating the trafficking route of illicit drugs.\[14\] Principal component analysis (PCA) on the other hand is instrumental in reducing data in hyperspace into more manageable dimensions. With data reduction, relationships within a large dataset are quickly assessed. Simultaneous employment of this multivariate approach and IR data has also been reported.\[15–19\] The significance of the current study is that since plastic films serve as the first accessible source of information upon submission of the case, timely forensic interpretations of this evidence will certainly help in decision making for police operational work.

In this study, we extracted forensic information from the IR spectral data obtained from the plastic packages that were used to contain illicit heroin. These data were used when the plastic packages were devoid of unique characteristics such as logo, color, and striation marks. In addition, the evidential strength of physical characteristics (e.g., film thickness, width, and length) is often limited compared to the chemical characteristics. In this analysis, we first distinguished the various polymeric types of plastic films at the macro level. Then, we triangulated the plastic types with the police information to get a snapshot of the heroin trafficking activity. At the micro level, we determined if the same type of plastic films showed quantitative spectral differences. Forensic interpretations associated with these variations were also made. In a nutshell, this study is divided into three sections: (1) qualitative classification of plastic types from 311 heroin cases, (2) quick validation of the statistical model for spectral variation analysis, and (3) statistical spectral variation analysis of the most frequently encountered plastic type by PCA.

**MATERIALS AND METHODS**

**Case Plastic Films**

Plastic packages in 311 illicit heroin cases submitted from four geographical locations were considered. In each case, the substance was transferred from the plastic package into a sampling bag, then the inner and outer surfaces of each plastic package were thoroughly cleaned with tissue paper. Width measurement was made on the plastic packages manually by a ruler (accuracy = 0.5 mm). Due to limited access to the samples, two representative spectral measurements were obtained from each case. The cleaned outer surface of the plastic package was scanned by a HazMatID portable IR spectrometer with the aid of a machine press. The examination was accomplished by the use of a HazMatID built-in diamond sensor (attenuated total reflectance) with integrated video monitoring. The number of scans was set at 64, with a resolution of 4, and the information was collected in absorbance mode from 4000 and 650 cm\(^{-1}\).

**Specimen Plastic Films**

Specimen plastic films were required for instrumental and statistical validation. Two sets of
specimens—A and B (both of Type 1-polypropylene-based identified by IR)—were prepared after the polymeric types were identified from the case plastic films. To ensure specimens A and B were quantitatively spectrally different in their film polymer, both were purchased commercially from different brands and in different widths. Specimen A simulated sample plastic films that were subjected to uncontrolled variables during IR analysis, while B acted as a control for system checkup.

1. To assess environmental and instrumental influences on the spectral data, a specimen plastic film marked “A” measuring 5.00 cm in width was used to evaluate the effects of optical contact between the film and the diamond surface. Two spots were marked on the same film to ensure polymeric makeup consistency during analysis, and each was subjected to IR measurement under a set of five different conditions. Four degrees of force (1×, 2×, 3×, and machine press) were applied on each spotted area of the film placed on the diamond stage. Another measurement was obtained with the diamond surface covered with a very thin layer of street heroin substance and under machine press. Examination was accomplished by a HazMatID portable IR spectrometer with the same setting.

2. To assess repeatability and reproducibility of the IR spectral response and sample stability, a batch of seven different plastic packets marked “B” measuring 7.40 cm in width was examined like the case plastic films to obtain 8 spectra at random on the same day and a total of 20 spectra on different days.

**Spectral Analysis**

As the HazMatID portable IR spectrometer was not furnished with a complete plastic polymer library, visual inspection and manual superimposition of spectral fingerprints were the chief methods to distinguish between the polymer types. For quantitative analysis of the most frequently encountered polymer type, significant peaks of selected spectra were processed by HazMatID software version 3.1, and the maximum absorbances of the selected peaks were used for statistical analysis. General statistics were performed with the Excel worksheet. IR data were statistically reduced by PCA using MiniTab 15 and SPSS version 18. Details on data pretreatment will be discussed.

**RESULTS AND DISCUSSION**

**Qualitative Classification at Macro Level**

A plastic film placed on the HazMatID sample stage with a built-in machine press required less than 2 min to obtain its spectra. With this daily-performance-checked instrument, five distinctive types of plastic polymer were identified from 311 heroin cases, namely Types 1–5 (Fig. 1 and Table 1), based on absorption bands. The true identities of these polymer types were not of interest since the objective was to discriminate the plastic films rather than to identify them. With reference to the literature, absorption bands over the ranges of 2950–2800 cm⁻¹, 1500–1350 cm⁻¹, and 1200–800 cm⁻¹ of Types 1 and 5 reveal that they show the characteristics of a polypropylene backbone. Types 2, 3, and 4 also collectively display the same absorption patterns over the IR range with bands at 2950–2800 cm⁻¹, 1460 cm⁻¹, and 720 cm⁻¹ that suggest a polyethylene backbone. As two IR spectra of Type 4 clearly showed extra absorption bands at 1000–1500 cm⁻¹ on the Type 2 backbone, we decided to classify it as an individual type. Weak variations in the spectra within the same type were also noticed in some plastic films. Causin et al. postulated that these variations could be ascribed to the presence of fillers, comonomers, and preoxidants that were added to the base polymers. As their signals were weak, quantitative assessment was not possible with minor variations. However, the intensities of the significant peaks of the similar types also measurably varied, and this was addressed in the subsequent section for spectral variation analysis.

For forensic interest, the plastic types at the operational level imply the mode of operation of the heroin packers/distributors. Out of 311 cases, Type 1 accounted for 92.93% of cases. Type 2 (0.96%), Type 3 (5.14%), Type 4 (0.32%), and Type 5 (0.64%) were relatively less prevalent. The frequencies of their encounters in four main geographical locations of interest, namely Kuala Lumpur (KL), Selangor (SL), Negeri Sembilan (NS), and Pahang (PH) are presented in Fig. 2.
Type 1 constituted the major proportion of cases submitted by the enforcement units of the four locations. This attests to the ubiquitous availability of Type 1 packages. It is also suggestive of cross-distribution of heroin packed by a single packer whose modus operandi is associated with Type 1. The preference of the packers toward this type could be attributed to the commercial availability of this plastic type at any outlet selling plastic materials and its reasonable strength in holding coarse heroin substances. Type 2 was common in KL and NS. Type 3 was the second largest type, although the inclination toward its use remained somewhat

<table>
<thead>
<tr>
<th>TABLE 1 Polymer Types Distinguished by IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic type</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

FIGURE 1 Five types of polymeric films encountered in packaged-heroin seizures. Types 1 and 5 are polypropylene-based, whereas Types 2–4 are polyethylene-based.
inconspicuous. The presence of Type 3 is obvious in KL, SL, and NS but not in PH. The use of Types 2 and 3 can be ascribed to the commercial use by local hawkers to pack food and hence its ready availability. Types 4 and 5 were rarely chosen, and their occurrence was associated with large plastic bags (>9 cm in width). Both Types 4 and 5 were found in samples seized in SL and KL respectively. Type 4 was the common type of fragile plastic bags used at supermarkets for packing wet materials, and it is not readily obtainable at every outlet selling plastic materials. Its rare occurrence is due to the thin film and not adequate for handling heavy masses like heroin especially for an undetermined period of distribution. So it is less common for trafficking purposes. The rare occurrence of Type 4 also suggests that this packer was operating on an ad hoc basis or on a small scale as the use of this plastic bag had not been evident in other seizures as well as in other locations. Of all cases, small plastic packets of Type 1 were prominent, and they were selected for spectral variation analysis.

Instrumental and Statistical Validation for Spectral Variation Analysis

As mentioned in the previous section, spectral variations were also observed in the Type 1 polypropylene-based films. Regardless of whether the differences are statistically significant, the instrumental performance and IR data-processing method must be validated beforehand. PCA is an ideal tool for decomposing a large data set into small but variability-rich dimensions. So, this statistical tool was chosen to maximize the spectral variations displayed by the cases plastic packets. In this section, only the Type 1 polypropylene-based small plastic packets (<9 cm in width) were considered. The following are the proposed steps for IR data pretreatment (instrumental and statistical validation) for spectral data analysis.

1. To ensure true homogeneity, variation in the width of the plastic packets in a single case should not exceed 0.5 mm. This maximum permitted variation (MPV) is the error associated with the use of a ruler, and thus homogenous samples should not show errors greater than this value.

FIGURE 3  (a–e) Five spectra of spot 1 obtained under different conditions. (f) Spectra of a street heroin sample highly cut with caffeine, which was the characteristic of the local samples. Contamination was largely ascribed to the peaks arising from caffeine.
The limit also allows for errors arising from shrinkage or expansion of the films due to environmental influences. Length was not used alongside because this variable was often deteriorated by unprofessional sealing.

2. Data-processing validation was achieved by specimen A. Optical contact may lead to differences in the intensities of absorbance. This was shown by the various effects on the spectral outcomes of the plastic film A (Fig. 3). Notably, air gaps created by using lower force between the plastic film and the diamond surface would lead to less IR-film contact, resulting in lower intensities. The intensities of the peaks increased with increasing force applied. However, they increased as a group rather than as a whole, whereby four peaks spanning across the range 2950–2800 cm⁻¹ increased irrespective of the two neighboring peaks at 1500–1350 cm⁻¹. In other words, merely taking the signal-to-noise findings will run a risk of data misinterpretation caused by poor optical contact arising from uneven film surface. Contamination on the other hand can affect the small peaks to a greater extent. Normalization can significantly reduce discrepancies in the peak intensity associated with optical contact and less likely with contamination. So three peaks at approximately 2948 cm⁻¹, 2914 cm⁻¹, and 2873 cm⁻¹ were normalized with reference to the fourth peak at 2834 cm⁻¹, while the sixth peak at 1374 cm⁻¹ was normalized to the fifth peak at 1456 cm⁻¹, and all the other small peaks were disregarded due to the relatively high errors associated with the low absorbance intensities. During normalization, the absorbance maxima of the selected peaks processed by HazMatID software were utilized. After normalization, all the affected peak intensities tend to show better agreement in the normalized form as expressed in their respective columns in Table 2, except the sixth peak which was affected by contamination. However, such contamination is not a factor in our study as the diamond surface and plastic films were thoroughly cleaned prior to scanning. Also, this was confirmed by the contamination-free spectra and result consistency from two representative spectra. Minimization of errors resulting from uneven applied force was displayed by expressing the differences in the normalized peak intensities between two corresponding peaks of spots 1 and 2 as a percentage. Table 2 reveals that the percentage difference in normalized data is smaller than the percentage difference in the original peak intensities. Hence, all IR data should be normalized before PCA so that any difference in the absorption can be solely attributed to the difference in the film material.

3. Instrumental performance and sample stability were achieved by assessment of within-day and between-day variations shown by specimens B. The findings in Table 3 show that normalization is able to minimize between-day variation to a significant extent. This means reduction of errors associated with uncontrolled variables (e.g., uneven force) while measurements were made. In a valid PCA, findings of A were supposed to show relationships, despite different force conditions. Findings of B measured under normal condition should be evenly and closely spaced.

<table>
<thead>
<tr>
<th>Spot</th>
<th>Original Peak number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x Force</td>
<td>1.68</td>
<td>1.95</td>
<td>1.00</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td>2 x Force</td>
<td>1.70</td>
<td>2.04</td>
<td>1.00</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td>3 x Force</td>
<td>1.69</td>
<td>2.00</td>
<td>1.01</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>Machine press (MP)</td>
<td>1.75</td>
<td>2.10</td>
<td>1.00</td>
<td>1.62</td>
<td></td>
</tr>
<tr>
<td>Contaminated</td>
<td>1.73</td>
<td>1.96</td>
<td>1.03</td>
<td>1.24</td>
<td></td>
</tr>
</tbody>
</table>

% Δ Normalized MP ^[11.66%]
% Δ Original MP ^[11.66%]

*Original IR peak intensities. ^=[(1.75 – 1.73)/1.73 × 100] = 1.16%.
^[(0.182 – 0.163)/0.163 × 100] = 11.66%.
to show natural random variation. Normalization can further enhance instrumental validity. Normalized data reduce the risks of false clusters (unwanted separation) within the same group and improve relationships of affected data of the same group. Four score plots of two datasets respectively from plastic films A and “B” accompanied by their respective percentage variability expressed as $\%V_1$ (first component) and $\%V_2$ (second component) are shown in Fig. 4. The findings of B are represented by black dots. The findings of A are expressed as pairs of

![Score plots](image)

**FIGURE 4** Score plots of (a) original peak intensities ($\%V_1 = 94.24\%$, $\%V_2 = 5.60\%$), (b) original peak intensities and widths ($\%V_1 = 89.09\%$, $\%V_2 = 7.74\%$), (c) normalized peak intensities ($\%V_1 = 50.71\%$, $\%V_2 = 34.96\%$), and (d) normalized peak intensities with widths ($\%V_1 = 55.08\%$, $\%V_2 = 28.00\%$).

**TABLE 3a** Repeatability and Reproducibility of Specimens B in Original Peak Intensities

<table>
<thead>
<tr>
<th>Peak no.</th>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M ± SD</td>
<td>0.183</td>
<td>0.220</td>
<td>0.108</td>
<td>0.104</td>
<td>0.110</td>
<td>0.174</td>
</tr>
<tr>
<td>Repeatability</td>
<td></td>
<td>0.002</td>
<td>0.004</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>(n = 8)</td>
<td>%RSD</td>
<td>1.07</td>
<td>1.97</td>
<td>1.74</td>
<td>0.80</td>
<td>0.81</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td>M ± SD</td>
<td>0.175</td>
<td>0.210</td>
<td>0.103</td>
<td>0.100</td>
<td>0.106</td>
<td>0.168</td>
</tr>
<tr>
<td>Reproducibility</td>
<td></td>
<td>0.012</td>
<td>0.016</td>
<td>0.007</td>
<td>0.005</td>
<td>0.005</td>
<td>0.009</td>
</tr>
<tr>
<td>(n = 20)</td>
<td>%RSD</td>
<td>6.96</td>
<td>7.79</td>
<td>6.64</td>
<td>6.65</td>
<td>4.62</td>
<td>5.58</td>
</tr>
</tbody>
</table>

**TABLE 3b** Repeatability and Reproducibility of Specimens B in Normalized Peaks

<table>
<thead>
<tr>
<th>Peak no.</th>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M ± SD</td>
<td>1.759</td>
<td>2.115</td>
<td>1.038</td>
<td>1.585</td>
</tr>
<tr>
<td>Repeatability (n = 8)</td>
<td></td>
<td>0.012</td>
<td>0.029</td>
<td>0.012</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>%RSD</td>
<td>0.68</td>
<td>1.38</td>
<td>1.19</td>
<td>0.89</td>
</tr>
<tr>
<td>Reproducibility (n = 20)</td>
<td>M ± SD</td>
<td>1.754</td>
<td>2.111</td>
<td>1.039</td>
<td>1.578</td>
</tr>
<tr>
<td></td>
<td>%RSD</td>
<td>0.80</td>
<td>2.02</td>
<td>1.13</td>
<td>1.49</td>
</tr>
</tbody>
</table>
bright shapes according to the five conditions in Table 2. Problems associated with original peak intensities are as follows:

i. Figs. 4(a) and 4(b) clearly display three false clusters of B with the original peak intensities, although only 20 findings were obtained under the machine-press condition.

ii. The pair of A under the machine-press condition (“bright triangles”) in Fig. 4(a) overlaps with B. They however are separated from B when a width variable was added in Fig. 4(b).

iii. The score plots 4(a) and 4(b) indicate exaggerated long-range relationships of the A findings that were affected by force and contamination.

The data normalization process can help to solve the following problems:

i. After data normalization, false clusters of B were obliterated, and an even distribution was obtained (Figs. 4(c) and 4(d)).

ii. When all data were measured under the machine-press condition, normalized IR data alone or together with width measurements are sufficient to contribute an ideal spread for clustering of distinct groups. Bright triangles of normalized A are separated from B in Fig. 4(c) and further separated by width measurement in Fig. 4(d). Normalized IR findings are therefore an optimized form for clustering similar types of polymeric films and with enhanced discriminative power in the presence of additional variables (e.g., width). Other variables such as film thickness are not discussed here because this study was aimed at making use of spectral differences.

iii. The first component axes of in Figs. 4(c) and 4(d) also indicate that the distances between the A findings are significantly reduced with a small expansion of the second component axes and hence a closer spread of the A points. The reduction of distances is vital for any deviations attributed to uncontrolled factors such as uneven force.

So, we propose to use this method for spectral variation analysis at the micro level. Besides, only the first two components of PCA were consistently employed for comparison because the subsequent components may not be meaningful with their negligible variability in certain cases (e.g., score plots 4(a) and 4(b) respectively showed 99.84% and 96.83% in their first two components).

Spectral Variation Analysis of Case Plastic Films at Micro Level

The ability of the HazMatID to retrieve quantitative data added more strength to data analysis. First, 197 cases (having plastic packets within the MPV) were carefully identified. For each case, the mean values of four normalized peak intensities (peaks 1, 2, and 3 were normalized to 4; peak 6 was normalized to 5) of two representative spectra retrieved and processed by the HazMatID software version 3.1 were chosen for statistical reduction. A total of 197 cases \(x\times 4\) normalized peaks = 788 variables were directly decomposed by PCA. Although most normalized data appear to display negligible differences in the selected case, the symbiosis of PCA and IR spectra can detect small spectral differences between samples\(^\text{[16]}\) and differentiate them through these small differences. As the inclusion of nonspectral variables such as width will affect spectral variation analysis using PCA, the spectral differences shown by the case plastic packets were analyzed according to their width in Fig. 5. Data points of B surrounded by a dotted polygon were included to serve as a control that collectively define a maximum natural deviation area within which any deviations between data points smaller than the polygonal area would suggest high similarity. Natural variation means the permitted spectral variation determined from within and between samples from a single source represented by B and determined from within and between days from the same instrument. Moving and rotating around the polygon on each score plot will help suggest if the spectral variation is due to natural variation or polymeric differences. The score plots 5(c) and 5(d) display poor similarities among the spectral data. This suggests that the plastic films used to pack the illicit heroin were likely not of the same batch/production line.

Taking the spectral differences with or without width variation in 197 cases into consideration, both score plots in Fig. 6 show similar patterns. It means that an additional width variable in Fig. 6(b) does not significantly change the general pattern on the first two components, although further separation (e.g., 192) or merging (e.g., 191) does occur in Spectral Variation Analysis of Case Plastic Films at Micro Level.
certain points. The spread of data was thus largely ascribed to the spectral differences. With the width variable, specimens B maintain their relatively random distribution with slight shifts in Fig. 6(b). Based on the PCA patterns, we could conclude that the plastic packages used in 197 cases were widely similar except for a few cases. Forensically, close agreements of the points (e.g., 190, 191, and 309) suggest that the same packer or different packers who purchased the same batch of plastic packets may be involved. In PH, films 64 and 176 are unlikely to belong to the production line of film 47 as they are marginally outside the maximum polygonal area. Film 38 is different from film 158 although both were found in KL. Likewise, both films 158 and 281 found in KL are noticeably different. It is also true in films 37 and 197 seized in NS. Dissimilarities suggest different batches of plastic films. This in turn implies that different packers or the same packer using different plastic films was involved. This preliminary information is very much useful for providing a gross snapshot of the heroin cases at the distribution level.

**FIGURE 5** Score plots of spectral variations of Type 1 plastic packets in their respective widths: (a) 10 cases (4.8–4.89 cm) with $\%V_1 = 56.86\%$ and $\%V_2 = 23.18\%$; (b) 11 cases (6.10–6.19 cm) with $\%V_1 = 63.41\%$ and $\%V_2 = 18.91\%$; (c) 92 cases (6.20–6.29 cm) with $\%V_1 = 57.86\%$ and $\%V_2 = 25.25\%$; (d) 58 cases (6.30–6.39 cm) with $\%V_1 = 57.65\%$ and $\%V_2 = 27.56\%$; and (e) 11 cases (6.40–6.49 cm) with $\%V_1 = 53.83\%$ and $\%V_2 = 20.92\%$. The widths were decided based on the 197 cases considered. Other widths not included because of their absence were in the data set or low prevalence for PCA. Score plots a and e show natural variation rather than difference in films defined by the rotated polygon. Score plots c and d have significant differences in certain plastic films.
CONCLUSIONS

The polymer type of plastic packages remains a potential item for forensic intelligence. Type 1 plastic films are frequently used by heroin packers because of their universal accessibility and physical robustness for containing hard substances. Rare occurrence of Type 4 suggests small-scale operation. Associating the polymer types with information supplied by enforcement units provides a preliminary route for forensic intelligence. Type 1 plastic packages using PCA gives useful indication about the polymer types with information supplied by enforcement units. With large quantities of Type 1 plastic packets being used, it was detected—regardless of whether they have the same width—was detected by the PCA. Better conclusions can be achieved when IR data are triangulated with other qualitative and quantitative data. To maximize the usefulness of spectral data, we suggest establishing a database for these plastic films so that the cases plastic films can be meaningfully compared.

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