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ABSTRACT

This work presents the results of a novel application for the fast on-site screening of cocaine and its main cutting agents in suspicious and confiscated samples. The methodology behind the novel application consists of portable electrochemical detection coupled with a peak-recognition algorithm for automated result output generation, validated both in laboratory and field settings. Currently used field tests, predominantly colorimetric tests, are lacking accuracy, often giving false positive or negative results. This presses the need for alternative approaches to field testing. By combining portable electrochemical approaches with peak-recognition algorithms, an accuracy of 98.4% concerning the detection of cocaine was achieved on a set of 374 powder samples. In addition, the approach was tested on multiple ‘smuggled’, colored cocaine powders and cocaine mixtures in solid and liquid states, typically in matrices such as charcoal, syrup and clothing. Despite these attempts to hide cocaine, our approach succeeded in detecting cocaine during on-site screening scenarios. This feature presents an advantage over colorimetric and optical detection techniques, which can fail with colored sample matrices. This enhanced accuracy on smuggled samples will lead to increased efficiency in confiscation procedures in the field, thus significantly reducing societal economic and safety concerns and highlighting the potential for electrochemical approaches in on-the-spot identification of drugs of abuse.

1. INTRODUCTION

Illicit drug trafficking has been an increasing problem, with record breaking numbers of seizures and seized quantities occurring during the last decade (e.g. 279% increase in cocaine seized in 2019 than in 2009).[1,2] The illicit drug market continues to grow, even during the worldwide COVID-19 pandemic. Trafficking organizations appeared to react to disruptions early in the pandemic, quickly returning to 'business as usual'. In fact, Germany recorded a record cocaine seizure of 16 tons in February 2021 (< 1 year into the COVID-19 pandemic), and the port of Antwerp recording a 7.2 ton seizure later that month. Since early 2021, the pace of drug trafficking has even risen above the pace prior to the pandemic.[1,3] Consumption numbers initially decreased during the pandemic, since a large proportion of illicit drugs are consumed in social environments (bars, nightclubs, festivals, etc.) which were inaccessible for over one year.[1] Further to stabilizing consumption and increasing trafficking rates, the United Nations (UN) expect a post-COVID-19 economic crisis, which would lead to increased poverty. As such, more people will become increasingly vulnerable to entering the illegal drug trafficking process. Therefore the UN expects a rise in global drug trafficking numbers over the next decade, particularly at cultivation sites in Latin America.[1] Due to increasing trafficking incidences year-on-year, pressure will mount on customs agencies to screen for illegal goods. For Western Europe, one particular regularly smuggled illicit drug is of interest: cocaine.

Customs services at airports and harbors are particularly keen to monitor passing cargo, luggage and people for the presence of cocaine. Currently, on-site screening is primarily performed using colorimetric tests, e.g. the Scott color test for cocaine. However, these tests are difficult to interpret and have proven unreliable due to their poor selectivity and vulnerability towards masking agents (e.g. pigments and colored matrices).[4-7] Alternative screening methods, mostly in the form of optical techniques like Fourier transform infrared (FTIR) and Raman spectroscopy, are becoming more accessible, with portable FTIR and Raman spectrometers on the market.[8] Such instrumentation is expensive, however, and commercially available optical methods tend to be unreliable for dark-colored samples due to increased absorption of irradiated light fluorescence.[9,10] Although most encountered cocaine samples on street level are white, smugglers are becoming increasingly inventive in concealing illegal substances, where one such method concerns incorporating cocaine into colored matrices (e.g. charcoal, fishmeal). Therefore, the color vulnerability of optical devices and color tests is an important issue.

The 'golden standard' analysis techniques for illicit drug identification and quantification involve gas/liquid chromatography coupled to mass spectrometry and flame ionization detection, respectively. Again, these techniques are expensive, involve laborious maintenance, require expert knowledge and are difficult to miniaturize. These techniques are therefore avoided for routine screenings of cocaine, thus color tests are routinely used, even in light of their unreliable, insensitive qualities.[11]

With a gap in low-cost, sensitive and accurate (cocaine) detection methods, other techniques must be evaluated. Such a technique, explored herein, concerns

electrochemistry. Electrochemical detection has the potential to offer accurate and fast detection, and is typically conducive to miniaturization allowing for straightforward, portable instrumentation for on-the-spot screening and analysis. Moreover, electrochemical approaches are generally inexpensive. Previous research has highlighted the potential of electrochemical approaches in illicit drug detection, mainly based on carefully developed voltammetric approaches to detect both illicit drugs and their cutting agents, either separately or simultaneously, albeit predominantly in laboratory settings.[12-25]

The foremost obstacle preventing the (commercial) use of electrochemical devices in the field is that customs personnel and other field workers do not possess the necessary electrochemical knowledge to interpret the output data. To tackle this, our group developed a research line concerning an algorithm, with the purpose of bringing electrochemical methods closer to society.[26] The main focus of this algorithm was dissected into two parts: (i) transforming the output data to aid sensitivity and allow increased discriminating power between signals of different compounds, providing specificity, and (ii) automatically translating the voltammetric output to character outputs indicating which (illegal) compounds are present in a given sample. In other words, generating a result output that allows field personnel to independently determine what is present in a given sample, without the need for technological specialists.

In this work, for the first time ever, all previously obtained knowledge concerning the electrochemical analysis of illicit drugs, cocaine in particular, is combined with the previously mentioned software algorithm, resulting in an electrochemical cocaine sensor ready to be used on-site.[6,19,25,27] Uniquely, this novel cocaine sensor was subsequently tested and validated with a large set (300+ samples)of confiscated samples, including typical (white) powders, as well as smuggled samples.

2. MATERIALS AND METHODS

2.1. Reagents and samples

All measured confiscated samples were provided by the National Institute of Criminalistics and Criminology (NICC, Brussels, Belgium), the Netherlands Forensic Institute (NFI, The Hague, The Netherlands) and Belgian Customs (Antwerp/Brussels, Belgium). Potassium monophosphate, potassium chloride and potassium hydroxide were purchased from Merck (Overijse, Belgium). A 20 mmol L^{-1} phosphate buffer (pH 12) containing 100 mmol L^{-1} KCl was prepared and the pH altered to 12 by adding 100 mmol L^{-1} potassium hydroxide solution and a pH-meter (913 pH/Conductometer, 2.914.0020, Metrohm, Switzerland). This buffer was used for all electrochemical measurements.

2.2. Instrumentation and apparatus

Square-wave voltammograms (SWV) were recorded using an EmStat Blue portable potentiostat (PalmSens, Houten, The Netherlands) with PSTrace 5.7 software. Disposable ItalSens IS-C screen printed electrodes (SPE) (PalmSens, Houten, The Netherlands), containing a graphite working electrode (diameter, Ø = 3 mm), a carbon

counter electrode, and a (pseudo) silver reference electrode were used for all measurements. For each measurement concerning powders, a small amount of sample (< 0.5 mg) was collected and added to a pre-filled Eppendorf safe-lock tube (Eppendorf N.V., Aarschot, Belgium) containing 1.5 mL of pH 12 phosphate buffer. The tube was closed and the contents firmly shaken for 5 s, after which 50 µL of the sample solution was added to the SPE surface (Figure S1). The sample preparation was slightly different for impregnated textile samples. In these cases, a 10 mm × 10 mm piece of sample textile was put in the Eppendorf tube with 1.5 mL of buffer. After 10 s of shaking, the solution was pipetted from the tube and a droplet put onto the SPE surface for analysis. The applied SWV parameters were: step potential of 5 mV, an amplitude of 25 mV and a frequency of 10 Hz, resulting in a measurement time of approximately 35 s. The potential was swept from −0.1 V to +1.5 V versus Ag/AgCl.

The raw measurement (current-voltage) data collected by PSTrace 5.7 was processed using Matlab R2018a software (Mathworks, Natick, MA, USA), including the Signal Processing Toolbox™. The data processing steps follow the same approach as published by Van Echelpoel *et al.*[26], using a top-hat filter combined with a peak identification algorithm approach. The top-hat filter is a so-called zero-area filter that has a central window with an odd number of channels *w* and two side windows each *v* channels wide. The value of the filter coefficients (*k* and h_k) follows from the zero-area constraint. The filtered (i.e. transformed) electrochemical response y_i^* is subsequently obtained by the convolution of the electrochemical response with the filter. The top-hat filter emphasizes signals in the SWV, making the approach more sensitive, aids the peak resolution and discriminative power between peaks, while removing any influences of an inconsistent continuum (background correction to zero).

Two parameters are defined to allow automated peak identification: the minimum peak height and the minimum peak prominence. The minimum peak prominence is measured by placing a marker on the top of a current peak. A horizontal line is then drawn through this marker until (i) it crosses the signal because it encounters a higher peak or (ii) it reaches the left or right end of the signal (Figure S2). Then, the minimum of the signal in each of the two intervals defined in the previous step is searched. This point is either a valley or one of the signal endpoints. The higher of the two interval minima specifies the reference level. The height of the peak above this level is its prominence. Each peak that has a value higher than the defined minimum peak height and minimum peak prominence is identified as a peak that will be processed further throughout the approach. The peak identification algorithm is also peak potential-based and allows detection of the following compounds: cocaine, levamisole, phenacetin, lidocaine, caffeine, paracetamol, hydroxyzine and diltiazem (Figure S3).

For the proposed application (cocaine detection) the factor *w* was set at 9, a value of −0.4 A.U. for minimum peak height and a value of 0.2 A.U. for minimum peak prominence was selected.

3. RESULTS AND DISCUSSION

The novel application presented in this work combines, for the first time, a portable, electrochemical detection strategy for cocaine with a peak-recognition algorithm for automated result output generation. The electrochemical detection strategy itself is based on the fusion of all previous research conducted at the A-Sense lab on the electrochemical behavior of cocaine (and its cutting agents) at unmodified SPE. This previous research involves e.g. understanding the influence of concentration, temperature and cutting agents on the electrochemical fingerprint of cocaine.[28] This knowledge on the electrochemical behavior of cocaine and its cutting agents was then integrated in the software algorithm, e.g. by defining the appropriate interval for cocaine and selecting the right set of algorithm parameters. As such an electrochemical cocaine sensor emerges that can realistically be used on-site in real scenarios. Uniquely, the novel sensor was subsequently validated on a large data set of real samples.

3.1. POWDER SAMPLES IN LAB SETTING

This aforementioned data set consists of a total of 374 randomly chosen unique samples, of which 303 contained cocaine (confiscated and delivered to NICC in the period 2013-2020). A histogram indicating the amount of cocaine present in the 303 cocaine-containing samples is shown in Figure 1 (also indicated in Table 1). It is clear that most samples contained high quantities of cocaine with a vast majority (82%) containing more than 50wt% cocaine and 92% contained over 30wt% cocaine. The average cocaine sample contained 69.3wt% cocaine and the total range of samples contained between 4.3wt% and 100wt% cocaine. The median sample contained 75.2wt% cocaine.

Figure 1: Histogram with the descriptive statistics of the cocaine quantities (weight percentage) present in 303 cocaine-containing powder samples seized 2013-2020. The quantities were established via GC-FID analysis.

Further to cocaine, the 374 samples contained a variety of cutting agents and other products. Table 1 gives an overview of the compounds present and how frequently they were present, along with average and median weight percentages for cocaine, levamisole, phenacetin, lidocaine, caffeine, paracetamol, hydroxyzine and diltiazem. The samples were all powders, except for two samples which were in a wax form. A total of 346 samples had a white color, while the remaining 28 were colored. Many other compounds have been identified in field samples, but are not as common as those given above. Therefore, the algorithm and study presented here was limited to just the aforementioned compounds.

An example measurement, with automated result output after applying the algorithm, is shown in Figure 2 for a sample containing 15.0wt% cocaine, 23.2wt% phenacetin, 16.0wt% lidocaine and 9.3wt% levamisole. Figure 2A represents the measured ‘raw’ voltammogram, which was then transformed to the output shown in Figure 2B following the application of the algorithm, stating which compounds were present in the sample. In addition to cocaine, the presence of cutting agents levamisole, phenacetin and lidocaine were successfully detected in this sample, showing that not only could relatively small amounts of cocaine be detected, but also its main cutting agents. More

importantly, the transformed data shows improved separation of cocaine and lidocaine signals and increased signal intensity compared to the raw voltammogram. This data subsequently illustrates two significant strengths of the developed data transformation algorithm: discriminating power and sensitivity.

Figure 2: SWV (top) and automated output (bottom) of a street sample containing 15.0wt% cocaine, 23.2wt% phenacetin, 16.0wt% lidocaine and 9.3wt% levamisole. Cocaine is indicated in red to emphasize the presence of an illicit compound.

Summarized results of electrochemical measurements for all 374 samples, knowing that 303 of the 374 samples analyzed contained cocaine, are as follows:

- total accuracy of 98.4% concerning the detection of cocaine,
- sensitivity of 99.0%, and
- specificity of 95.8%.
- In total, there were 3 false positive and 3 false negative results recorded.

Electrochemical results for the main cutting agents levamisole, phenacetin and lidocaine were also numerically analyzed since customs and law-enforcement personnel could use the presence of such compounds as an indication to link specific samples to specific trafficking organizations. Results concerning the presence of cocaine, levamisole, phenacetin and lidocaine using the electrochemical approach are summarized in Table 2.

The so-called ‘electrochemical fingerprint’ is an advantage of the electrochemical sensor compared to the color test, which only indicates the presence of cocaine, and no other cutting agents.[28] Another advantage of the electrochemical/algorithm approach is the improved accuracy compared to the color test.[6] The other cutting agents incorporated in the algorithm (levamisole, phenacetin, lidocaine, caffeine, paracetamol, hydroxyzine and diltiazem) were not included in the numerical results since they are encountered in few cases and/or at low concentrations, which would skew the statistical value of these results.

The accuracy for the detection of levamisole, phenacetin and lidocaine is lower (88.5%-95.7%) compared to cocaine (98.4%). Even so, such accuracies demonstrate the strong specificity of the electrochemical/algorithm approach, having generated only one false positive result each for levamisole and phenacetin for 206 and 103 samples, respectively. The reduced sensitivity compared to cocaine likely results from typically low concentrations of cutting agents present in the cocaine samples. 69.3wt% of cocaine is given on average, while average concentrations are considerably smaller for levamisole (11.0wt%), phenacetin (23.6wt%) and lidocaine (4.7wt%). For levamisole, false negative results (42) mainly concerned samples containing < 15.0wt% levamisole. For phenacetin, all 15 false negative results concerned samples containing < 2.0wt% phenacetin, highlighting that the detection technique is intrinsically sensitive towards phenacetin detection. In addition, the average phenacetin content in the samples was 23.6wt%, illustrating that these samples with a content under 2.0wt% are less common. For lidocaine, all 20 false negative results

concerned samples containing < 10.0wt% lidocaine, of which 80% contained < 5.0wt% of lidocaine. Overall, it is deduced that the intrinsic sensitivity could be better than current statistics reflect. No false positive detections occurred for lidocaine, further emphasizing the specificity towards lidocaine detection.

The detection of the cutting agents remains a useful investigative tool despite the reduced accuracy for the cutting agents compared to cocaine. The detection of cutting agents, however, is typically not a necessity. The main focus remains the detection of drugs of abuse, i.e. cocaine, which was detected accurately in 98.4% of the 374 cases.

3.2. OTHER SAMPLE MATRICES IN LAB SETTING

Cocaine traffickers are increasingly inventive day-by-day in concealing their product by, for instance, forming cocaine complexes with other materials or impregnating clothing with cocaine. These type of samples, certainly the complexes, typically pose problems for colorimetric and/or optical detection methods, especially if they are dark in color.

The cocaine complexes studied in this work were all colored, thus showing no visible resemblance to cocaine. Four samples were analyzed where cocaine was detected for 100% of the samples using the electrochemical sensor. The appearance of the samples is shown in Figure S4 of the supporting information, and electrochemical results given in Figure 3. For each sample, a cocaine peak is observed at approximately 0.83 V (*vs.* pseudo Ag reference electrode).[6]

Confirmatory analysis by the Dutch forensic institute (NFI) provided further information about the contents of the samples. Sample A contained 51.0wt% cocaine HCl, and insignificant amount of phenacetin. Other compounds such as iron and sulfur were also detected (likely iron thiocyanate). Sample B contained 16.1wt% of cocaine HCl, as well as iron thiocyanate. Sample C contained 8.0wt% of cocaine HCl in an inorganic matrix containing silicon and magnesium (likely talcum powder), as well as iron and chlorine. Sample D contained 20.0wt% of cocaine HCl, low amounts of natural cocaine by-products and aminopyrine. Sample D also contained herbal powder (from Columbia), as well as elevated concentrations of iron and chlorine. Colorimetry produced false negatives for all four samples, whilst the electrochemical approach produced positive (correct) results for all four samples A-D.

Figure 3: SWVs (current-voltage)and automated outputs (signal-voltage) of four cocaine complex samples A-D pictured in Figure S4.

Another method used to smuggle cocaine through customs is to saturate pieces of clothing in concentrated cocaine solutions and allow them to dry. The clothing can then be packed as usual in travel cases or cargo shipments. A selection of samples is shown in Figure S5 of the supporting information. A full overview of the samples analyzed with the electrochemical sensor is presented in Table 3. The samples had a cocaine content between 10.0 and 18.0wt%. For the samples shown in Figure S5, the full results are given in Figure 4. Cocaine was detected in all of the samples, and even the presence

of levamisole was demonstrated in all four samples. The combined results of the cocaine complexes and clothing samples prove the electrochemical sensor is sensitive to the detection of cocaine in complex matrices, where traditional color tests and optical techniques often fail.

Figure 4: SWVs (current-voltage) and automated outputs (signal-voltage) of four cocaine impregnated clothing samples pictured in Figure S5.

3.3. SAMPLING IN FIELD SETTINGS

A collaboration with Belgian Customs and the Federal Judicial Police enabled the testing of the electrochemical sensor in real field settings, such as the Port of Antwerp. Some measurements were performed on already confiscated goods, while others were performed during live interventions, illustrating how routine check-ups are performed in the field and providing insights and feedback on the requirements for on-site cocaine detection. These samples often involved cocaine hidden in other matrices like fishmeal, charcoal, clay minerals, salt and fruit juices. Photographs of a selection of these samples are given in Figure S6 in the supporting information. A summary of all performed measurements is given in Table 4, where 100% of electrochemical sensor measurements produced the correct results (following confirmatory analysis using chromatographic approaches). Full electrochemical results from the application of the developed algorithm are shown in Figure 5 and Figure 6. All samples containing cocaine (1-3, 6, 7, 9-12, and 15) exhibited a characteristic cocaine peak around 0.82 V (*vs.* pseudo Ag reference), and are correctly assigned to cocaine by the peak recognition algorithm. All other samples correctly did not show this characteristic peak, and as such are not assigned to cocaine by the peak recognition algorithm.

Figure 5: Automated result outputs for samples 1-10 given in Table 4 with indicated result: true positive (TP), true negative (TN), false positive (FP) or false negative (FN).

Figure 6: Automated result outputs for samples 11-17 given in Table 4 with indicated result: (TP), true negative (TN), false positive (FP) or false negative (FN).

The selection of samples analyzed in the field featured positive cocaine samples, and several samples in which cocaine is mixed. No false positive or false negative results were obtained, emphasizing the promising potential of the electrochemical/algorithm approach to be used by customs agents/at borders. There are three main reasons to seriously consider employing such technology in field settings:

(i) **accuracy** – far outweighing the accuracy of color tests,
(ii) **added value** for (darkly) colored samples and complex matrices which are increasingly common,

(iii) and **user-friendly** measurements – requires no expertise thanks to the algorithm and fully portable equipment.

In addition, the electrochemical method offers other significant advantages such as low detection limits, short analysis times and automatic report generation. To compare and summarize different testing strategies, Table 5 provides a performance comparison of the state-of-the-art on-site detection tools for illicit drugs: electrochemistry, color testing and portable Raman/IR. Most notable is the improved compatibility with different samples and accuracy of the electrochemistry/algorithm approach compared to color tests and spectroscopy. Furthermore, the electrochemical/algorithm technique offers information on the illicit drug and its cutting agents, whereas color tests and portable spectroscopy only indicate the presence of an illicit drug. Again, it is clear that the electrochemical method offers versatility, accuracy and sensitivity to be a serious asset to law enforcement agencies in their war on drugs.

4. CONCLUSIONS

Continuously increasing numbers in illicit drug trafficking and the flaws of currently used screening tests emphasizes the need for new approaches for on-site drug screening in bulk materials. Electrochemical methods, particularly involving screen-printed electrodes, offer accuracy, low cost, portability and ease-of-use. However, the interpretation of the scientific output should be performed automatically in order for electrochemistry to be a useful tool for end-users with little-to-no electrochemical expertise.

Our findings show that, by combining previous work concerning the voltammetric detection of cocaine and its main cutting agents, and the development of data filtering and peak recognition algorithm, a successful alternative for on-site screening of cocaine could be achieved. A cocaine detection accuracy of 98.4% was obtained using such methods with powder samples. Moreover, complicated sample matrices involving cocaine metal complexes, clothing, fishmeal and charcoal posed no problems for the electrochemical/software approach, in both laboratory and field settings. These findings provide significant promise for the proposed strategy to be used in real-time screening situations, with an added value for colored samples, which regularly cause problems for colorimetric and optical detection strategies.

The successful demonstration of this electrochemical cocaine sensor on a large set of powder samples paves the way for the development of similar electrochemical illicit drug sensors. Besides, further work will involve further fine-tuning of the peak recognition software, as this is a process of continuous improvement. Finally, efforts are made towards developing a more convenient sampling method. Overall, this work forms a milestone in the development of on-site electrochemical illicit drug sensors, proving its worth and grand potential in a real, applied context.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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TABLES

Table 1: List of compounds present in the samples (identified via GC-MS) along with their frequency and average and median weight percentages (wt%), quantified via GC-FID.

Compound	*Number of samples*	*Average wt%*	*Median wt%*
Cocaine	303	69.3	75.2
Levamisole	206	11.0	9.8

Phenacetin	104	23.6	16.9
Lidocaine	43	4.7	4.0
Caffeine	68	13.6	3.7
Paracetamol	18	47.3	56.5
Hydroxyzine	16	3.4	1.3
Diltiazem	12	2.3	0.5

Table 2: Key statistics describing the performance of the electrochemical sensor towards the detection of cocaine and the main cutting agents levamisole, phenacetin and lidocaine.

Compound present	*No. samples*	*True positives*	*True negatives*	*False positives*	*False negatives*	*Accuracy*	*Sensitivity*	*Specificity*
Cocaine	303	300	68	3	3	**0.984**	0.990	0.958
Levamisole	206	164	167	1	42	**0.885**	0.796	0.994
Phenacetin	104	88	270	1	15	**0.957**	0.854	0.996
Lidocaine	43	23	331	0	20	**0.947**	0.535	1.000

Table 3: Clothing samples analysed at NFI along with the amount of cocaine present and the result of the sensor.

Sample	*Cocaine content (wt%)**	*Sensor Result*
Sock	18	**Cocaine + levamisole**
Shorts	14	**Cocaine + levamisole**
Shorts	10	**Cocaine + levamisole**
T-shirt	16	**Cocaine + levamisole**
Towel	15	**Cocaine**
T-shirt	18	**Cocaine + levamisole**
Shirt	14	**Cocaine + levamisole**
Jogging pants	15	**Cocaine**
Polo	16	**Cocaine**
Jeans	10	**Cocaine + levamisole**
Pants	14	**Cocaine**

*Weight % acquired via GC-FID

Table 4: Overview of all analysed samples in a field setting.

No	*Samples*	*Sample appearance*	*Live intervention?*	*Total No. analysed samples*	*Sensor Result*	*True Result*[‡]
1	Cocaine mixed in fishmeal*	Brown powder	NO	1	**Cocaine**	Cocaine
2	Cocaine brick	White block	NO	1	**Cocaine**	Cocaine
3	Cocaine powder	White powder	NO	1	**Cocaine + levamisole**	Cocaine
4	"super food"*	Brown powder	NO	1	**Negative**	Negative
5	"Inca Kola"*	Yellow liquid	NO	1	**Negative**	Negative
6	Cocaine powder	White powder	NO	1	**Cocaine + levamisole**	Cocaine
7	Cocaine bricks hidden in salt bags	White block	YES	1	**Cocaine**	Cocaine
8	Salt in bags	White grains	YES	3	**Negative**	Negative
9	Cocaine mixed in red powder*	Red powder + grains	NO	1	**Cocaine**	Cocaine
10	Red powder*	Red powder + grains	NO	1	**Cocaine**	Cocaine
11	Cocaine solved in fruit juice*	Dark red liquid with pulp	NO	1	**Cocaine**	Cocaine
12	Cocaine mixed in kaolin clay*	Light brown fine powder	YES	3	**Cocaine**	Cocaine
13	Kaolin clay*	Light brown fine powder	YES	177	**Negative**	Negative
14	Manure*	Small dark brown bulbs	YES	105	**Negative**	Negative
15	Cocaine mixed in charcoal*	Black coals/powder	NO	6	**Cocaine**	Cocaine
16	Charcoal*	Black powder	YES	42	**Negative**	Negative
17	Hard Coal powder*	Black powder	YES	46	**Negative**	Negative

Collaboration with (1) Federal Judicial Police Antwerp; (2) Customs Brussels Airport; (3) Customs Port of Antwerp Linkeroever; (4) Belgian Customs – Administration

*These samples were impossible to detect with color tests

‡ Result as was communicated by the law enforcement and customs personnel, only concerning the presence of cocaine, after further analysis for confirmation

Table 5: Comparison of the state-of-the-art illicit drug on-site sensing tools.

Quality	*Electrochemistry*	*Color tests*	*Portable Raman/IR*
Compatibility with Nature of Sample	Colored + Non-colored powders + Solutions + cocaine complexes	Only non-colored powders (specific tests per drug)	Mostly non-colored powders (fluorescence background for (most) colored samples)
Amount of sample needed	Nanogram	Milligram	Milligram
Selectivity	High	Low	High
Accuracy	High (>98 %)	Low	High (non-colored)
Analysis time	< 1 minute	< 1 minute	1-2 minutes
Interpretation of results	Software based	Color change	Software based
Output	Info on compound + cutting agents	Only Yes/No	Compound
Portability & user friendliness	High	High	Low-High (depending on size and weight)