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Title	The analysis of textiles associated with decomposing remains as a natural training aid for cadaver-detection dogs
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Abstract

Cadaver-detection dogs are employed by law enforcement agencies to locate human remains. The ability of cadaver-detection dogs to locate human remains relies heavily on the use of effective training aids. Cadaver-detection dogs may be trained using a variety of materials ranging from natural scent sources to synthetic materials. Natural scent sources are typically considered to be the most effective training aids; however, there is concern that using individual tissue types as natural training aids may not be indicative of the scent of an intact human cadaver. The objective of this work was to determine how well textiles associated with decomposing remains retain and mimic the odour of natural training aids. To test this, the chemical odour profile of textile samples collected from decomposing porcine remains that were buried clothed in 100% cotton t-shirts was examined. Throughout various stages of decomposition, the pig carcasses were exhumed and cotton samples were obtained. The volatile organic compound (VOC) profile of the textiles was collected using headspace solid phase microextraction (HS-SPME) and analysed using comprehensive two-dimensional gas chromatography – time-of-flight mass spectrometry (GC×GC-TOFMS). This study provides evidence that textiles associated with decomposing remains may represent a useful natural training aid with a VOC profile reflective of a large subset of cadaveric decomposition odour. The odour profile is dynamic and changes over time suggesting that obtaining textiles from different postmortem intervals would be useful for providing training aids that represent the full spectrum of decomposition odour that cadaver-detection dogs may encounter during a search.

Keywords	Forensic taphonomy; Buried remains; Textiles; Cadaver-detection dogs; GC×GC-TOFMS
Manuscript category	Technology Readiness Level 1

Corresponding Author	Katie Nizio
Corresponding Author's Institution	University of Technology Sydney
Order of Authors	Katie Nizio, Maiken Ueland, Barbara Stuart, Shari Forbes

Suggested reviewers	Chris Tipple, Robert Janaway, Lauryn DeGreeff, Mary Cablk

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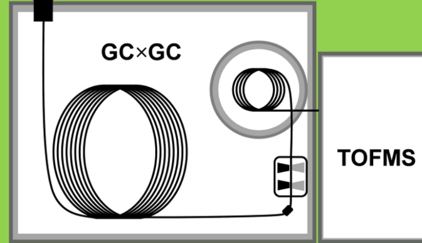

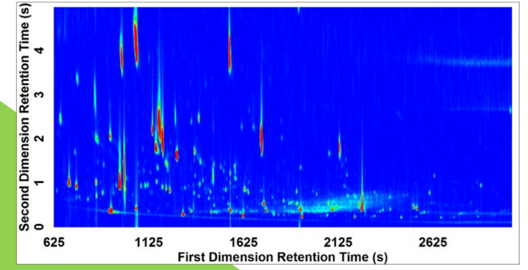

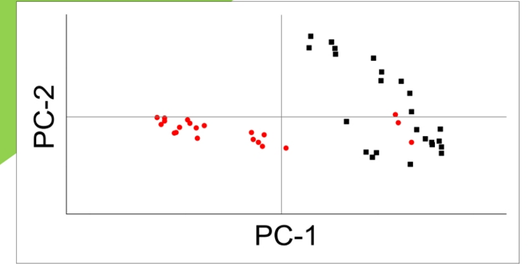

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The analysis of textiles associated with decomposing remains as a natural training aid for cadaver-detection dogs

Katie D. Nizio[a,1,*], Maiken Ueland[a,1], Barbara H. Stuart[a], Shari L. Forbes[a]

[a] University of Technology Sydney, Centre for Forensic Science, PO Box 123, Ultimo NSW 2007, Australia; E-mails: katiednizio@gmail.com (K.D.N.), maiken.ueland@uts.edu.au (M.U.), barbara.stuart@uts.edu.au (B.H.S.), shari.forbes@uts.edu.au (S.L.F.)

[1] These authors contributed equally to this work.

* Corresponding Author
Katie D. Nizio
Email: katiednizio@gmail.com

Abstract

Cadaver-detection dogs are employed by law enforcement agencies to locate human remains in cases of missing persons, suspected homicides and following natural or man-made disasters. The ability of cadaver-detection dogs to locate human remains relies heavily on the use of effective and reliable training aids. Cadaver-detection dogs may be trained using a variety of materials ranging from natural scent sources (e.g. flesh, bone, blood or decomposition soil) to synthetic materials (e.g. Pseudo™ Scents). Commercially available synthetic scents often have an overly simplistic chemical composition that is inconsistent with decomposition odour. Therefore, natural scent sources are typically considered to be the most effective training aids; however, there is concern that using individual tissue types as natural training aids may not be indicative of the scent of an intact human cadaver. The objective of this work was to determine how well textiles associated with decomposing remains retain and mimic the odour of natural training aids. To test this, the chemical odour profile of textile samples collected from decomposing porcine remains that were buried clothed in 100% cotton t-shirts was examined. Throughout various stages of decomposition, the pig carcasses were exhumed and cotton samples were obtained. The volatile organic compound (VOC) profile of the textiles was collected using headspace solid phase microextraction (HS-SPME) and analysed using comprehensive two-dimensional gas chromatography – time-of-flight mass spectrometry (GC×GC-TOFMS). This study provides evidence that textiles associated with decomposing remains may represent a useful natural training aid with a VOC profile reflective of a large subset of cadaveric decomposition odour. The odour profile is dynamic and changes over time suggesting that obtaining textiles from different postmortem intervals would be useful for providing training aids that represent the full spectrum of decomposition odour that cadaver-detection dogs may encounter during a search. This information is particularly beneficial for law enforcement agencies searching for effective and reliable cadaver-detection dog training aids.

Keywords: *Forensic taphonomy; Buried remains; Textiles; Cadaver-detection dogs; Natural training aids; GC×GC-TOFMS*

Abbreviations: ^{1}D, first dimension; ^{2}D, second dimension; DVB/CAR/PDMS, divinylbenzene/carboxen/polydimethylsiloxane; F_{crit}, critical value; GC-MS, gas chromatography – mass spectrometry; GC×GC-TOFMS, comprehensive two-dimensional gas chromatography – time-of-flight mass spectrometry; HS-SPME, headspace solid phase microextraction; NIST, National Institute of Standards and Technology; PC-1, first principal component; PC-2, second principal component; PCA, principal component analysis; PDMS/DVB, polydimethylsiloxane/divinylbenzene; *S/N*, signal-to-noise ratio; TIC, total ion current; TVOCs, total volatile organic compounds; VOCs, volatile organic compounds

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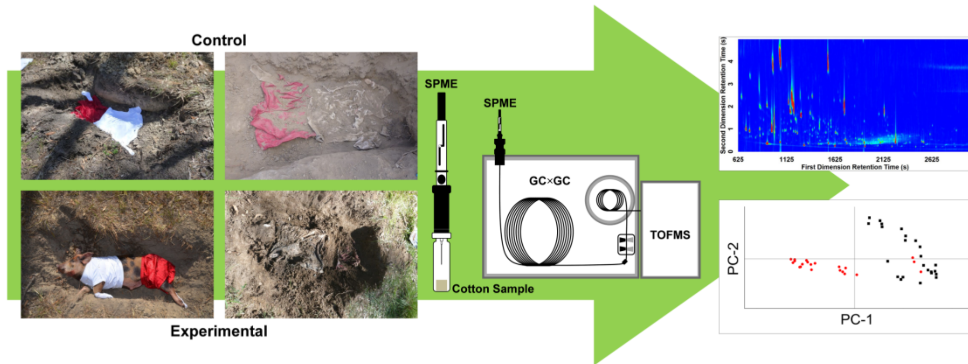
Graphical Abstract



1. Introduction

The innate ability of canines to locate and hunt prey makes them an ideal candidate for use as a scent-detection tool. Both wild and domesticated canines have a natural ability to detect the scent of their prey [1], an ability that can be used to train canines towards almost any desired scent. The use of canines in a forensic investigation dates to the 1800s, when bloodhounds were used in an attempt to locate Jack the Ripper in England [2]. Currently canines are used for the detection of drugs, explosives, agricultural products, accelerants, currency, missing persons, human remains and certain diseases. Cadaver-detection dogs are specially trained canines employed by law enforcement agencies to locate human remains in cases of missing persons believed dead, suspected homicides and following natural or man-made disasters. These canines evolved when handlers observed that the search and rescue dogs, trained to locate living humans, would lose their tracking ability once the individual was no longer alive, causing their scent to change [3]. Cadaver-detection dogs are still currently one of the preferred search methods for the localisation of human remains as they can cover large areas rapidly and can work both day and night [4,5].

The ability of cadaver-detection dogs to detect human remains relies heavily on the use of effective aids during training. Several materials, both natural and man-made can be used when training these dogs on a specific target odour. Natural training aids include biological tissues such as blood, bone or flesh, decomposition fluid or soil that has been in contact with decomposing remains [1]. Although ideal, the use of whole human cadavers for training is uncommon due to the ethical and legal restrictions associated with acquiring bodies. In addition to natural training aids, synthetic scents have also been developed such as Pseudo™ Scents. These man-made scents are easier to obtain as there are fewer ethical restrictions than those associated with natural training aids, and the synthetic scents are easier to store. Despite these advantages, commercially available synthetic scents often have an overly simplistic chemical composition that is not representative of decomposition odour [6,7], and in some cases can also comprise hazardous chemicals. Cadaverine and putrescine, two very odorous compounds often associated with decomposition, are commonly found in synthetic scents [8]. Although these scents are associated with human decomposition, they also result from the decomposition of any organic matter and are thus not human specific [9].

Due to the current inconsistencies associated with synthetic scents, natural training aids are considered more reliable and provide a better representation of the scent of human remains. However, Hoffman et al. [10] demonstrated that the odour produced from individual tissue samples (e.g. blood, muscle, skin, adipocere, fat, bone, teeth, etc.) shared similarities, but varied enough in their odour profile that care should be taken when using a specific individual tissue type as a cadaver-detection dog training aid. The use of individual bones, flesh and blood samples as training aids may not provide an adequate odour representation of a cadaver or intact human remains. An alternative

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training aid that may provide a more comprehensive profile than using bone, blood or specific tissue samples is the use of textile samples that have been in contact with decomposing remains. The use of textiles as training aids is beneficial over the use of bones or blood as they can trap scent molecules from the whole body rather than specific tissues types [11]. Textiles are commonly found in association with decomposing remains [10,11], either fully or partially clothed. As the remains decompose the resulting fluid released will cause the clothing to become stained. It has already been established that decomposition fluid will be absorbed into textiles and the fluid composition will change over time [12]. Additionally, fluid generated by decomposing remains can become embedded in-between the fibres of certain textile types, and might thus remain trapped as decomposition odour for longer than the remains. Cadaver-detection dogs are often trained on multiple training aids to ensure that the full range of decomposition odour is accounted for and that the remains can be successfully located.

The decomposition process is initiated the moment the heart stops beating. The process of breaking down the soft tissue to completion may take as little as days or progress slowly for years. Initially the pH of blood will decrease and the skin colour will fade in a process known as pallor [13]. During this process the early insect colonisers such as blow flies (*Calliphoridae*) and flesh flies (*Sacrophagidae*) arrive at the corpse [13]. The arrival of insects to the remains demonstrates that a scent is being emitted from the body. This scent will change and amplify as internal bacteria break down the macromolecules in the body. The breakdown causes the release of gases (i.e. volatile organic compounds; VOCs) such as methane and hydrogen sulfide. This large gas accumulation inside the remains will eventually cause the skin to rupture, effectively releasing the gases. During this period the strong odour anecdotally associated with decomposing remains is detected.

The location of human remains greatly impacts the decomposition process. Whether the remains are deposited on the surface or buried changes the immediate surrounding environment and can alter access by insects and other scavengers. Temperature aboveground is generally higher than below the surface [14,15]. Burial environments tend to result in decomposition over a longer period of time due to this temperature difference as well as due to the protection of the remains from scavenging, large and small [13] and general weathering activities [15]. As the process of decomposition in a burial environment is generally slower than a body decomposing on the surface, it is hypothesised that a burial environment might allow the analysis of the VOC profile from textiles for a longer time period.

Headspace solid phase microextraction (HS-SPME) combined with gas chromatography – mass spectrometry (GC-MS) has been used to identify trace amounts of volatile compounds emitted from a variety of forensic specimens [3,16]. A previous study by Zhu et al. [17] resulted in the development of a method used to detect six target VOCs along with the total volatile organic compounds (TVOCs) from textile samples using HS-SPME and GC-MS. The one-dimensional targeted GC-MS analysis

was deemed successful; however, would be unlikely to provide sufficient resolution for the analysis of VOCs from textiles associated with decomposed remains. Decomposition odour has previously been reported to consist of a complex mixture of VOCs [18–24] and it is still not known which VOCs are responsible for the detection and localisation of remains by cadaver-detection dogs. The initial decomposition odour studies also used GC-MS for VOC analysis, however, due to the complexity of the resulting profiles, comprehensive two-dimensional gas chromatography – time-of-flight mass spectrometry (GC×GC-TOFMS) instrumentation was introduced. GC×GC employs a second dimension GC column for further separation of the eluent from the first dimension column, and has been shown to provide increased peak capacity, higher resolution separations and improved sensitivity, providing a more comprehensive VOC profile [25]. The current study used HS-SPME-GC×GC-TOFMS to investigate the VOC profile emitted from textiles buried with decomposing remains over a two year period. The objective was to investigate how well the odour retained in clothing associated with these remains reflected the VOC profile of decomposition typically reported in the literature for humans and human analogues. This information will provide further insight into the value of textiles as a training aid for cadaver-detection dogs.

2. Materials and Methods

2.1. Experimental Design

Field experiments consisted of burying and subsequently exhuming a total of seven pig carcasses (*Sus scrofa domesticus L.*) at various intervals over a 24 month period (January 2013 – January 2015). Pigs were chosen for this study as they are widely accepted as human decomposition analogues in taphonomic studies due to their similarity in internal anatomy, fat distribution, size of chest cavity, skin, gut flora and lack of heavy fur [26]. Pigs were purchased postmortem as excess stock from Hawkesbury Valley Meat Processors, a licenced abattoir in Wilberforce, NSW, Australia confirmed to follow established animal welfare guidelines. All pigs were killed using captive-headbolt, the standard procedure employed in Australian abattoirs. The carcasses were wrapped in a large polyethylene tarpaulin and transported to the field site within an hour of death. Following the guidelines of the *Australian Code for the Care and Use of Animals for Scientific Purposes* (8th ed. 2013) (http://www.nhmrc.gov.au/guidelines-publications/ea28), animal ethics approval was not required for this study because the experimental subjects were: 1) purchased postmortem; and 2) not killed specifically for the purposes of this research.

The field site is an open eucalypt woodland located on the Cumberland Plain in Western Sydney, NSW, Australia (33° 38S, 150° 39E). The land is privately owned by the University of Technology Sydney and has been approved for research and educational purposes. The soil consists of layers of sandy clay topsoil to a depth of approximately 0.70 – 1.00 m, shale clays to a depth of approximately

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358 1.50 – 1.80 m and yellow and grey sandstone bedrock beyond 1.50 – 1.80 m. The topsoil is mostly
359 acidic, typically ranging between pH 4 – 5 throughout the year.
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361 The seven pig carcasses, weighing approximately 70 kg each, were clothed in 100% cotton t-shirts
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363 (Alpha Brand, Kmart, Broadway, NSW, Australia) prior to burial in individual experimental graves.
364 Cotton was chosen for this study as it represents a textile that is commonly worn and often associated
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366 with human remains. Seven cotton t-shirts were also buried in individual graves in the absence of
367 remains to serve as control samples. All graves were dug a minimum of 3 m apart (with a minimum of
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369 5 m between the control and experimental graves) to a depth of 50 cm using an excavator and were
370 backfilled using an excavator. The clothed pig carcasses and control textiles were exhumed after 1, 3,
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372 6, 12, 18 and 24 months post-burial.
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374 After exhumation, the textile samples were packaged into small paper envelopes, placed into
375 individually labelled paper bags and stored in a cooler for transportation to the laboratory. Paper was
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377 selected as the packaging material in order to prevent the textile samples from storing moisture and
378 degrading during transport and storage. To prevent bacterial and fungal growth the textile samples
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380 were air-dried under ambient temperature by hanging vertically inside a laboratory fume cupboard,
381 and any adhering tissue, soil or hair was removed after drying. Using sterilised scissors, triplicate
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383 1 × 1 cm cotton samples were collected from each experimental and control textile. Triplicate
384 1 × 1 cm cotton samples were also collected from a t-shirt prior to burial (referred to as day 0 control
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386 textiles) for the purpose of determining background VOCs associated with the cotton textiles. The
387 scissors were washed with acetone between each replicate and between experimental and control
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389 samples. The 1 × 1 cm cotton samples were placed into individual 20 mL headspace vials, sealed
390 airtight with a screw cap containing a 1.3 mm thick polytetrafluoroethylene/ silicone septum (Sigma-
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392 Aldrich, Castle Hill, NSW, Australia) and stored at -18 °C prior to analysis. VOC profiles of the
393 cotton samples were collected using HS-SPME and analysed using GC×GC-TOFMS.
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395 *2.2. HS-SPME Sample Collection*
396 Based on previous literature examples that used SPME for the headspace collection of VOCs
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398 produced from textiles [27] and decomposing remains [3,10,28–30], two different SPME fibres were
399 chosen for testing using the experimental textile samples collected after 6 months post-burial:
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401 namely a 65 μm polydimethylsiloxane/divinylbenzene (PDMS/DVB) fibre and a 50/30 μm
402 divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) fibre. Following optimisation of
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404 other parameters, the DVB/CAR/PDMS fibre (50/30 μm, 24 Ga Stableflex; Supelco, Bellefonte, PA,
405 USA) collected the widest possible range of compounds in the test samples and was therefore chosen
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407 for the headspace collection of VOCs in this study. Before first use, the fibre was conditioned for 60
408 min at 270 °C in the GC×GC sample inlet, according to the manufacturer's recommendations. Fibre
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410 reconditioning was performed for 5 min at 250 °C at the beginning of each sampling day. A fibre
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blank was completed before sampling and after every 3 sample collections. Prior to sample collection, the SPME fibre was pre-loaded with an internal standard [31] by exposing the fibre to the headspace of a 200 µL solution of 100 ppm bromobenzene (GC grade, Sigma-Aldrich), prepared in methanol (HPLC grade, Sigma-Aldrich), inside a sealed headspace vial for 15 s at room temperature. After incubating the sample vial for 10 min in a dry bath heating block (Thermoline Scientific, Wetherill Park, NSW, Australia) at a constant temperature of 40 °C, sample extraction was performed by exposing the SPME fibre to the headspace within the sample vial for 10 min while the sample vial was continuously maintained at 40 °C.

2.3. GC×GC-TOFMS Sample Analysis

A Pegasus® 4D GC×GC-TOFMS system (LECO, Castle Hill, NSW, Australia) equipped with a liquid nitrogen cryogenic quad jet modulator was used for sample analysis. The column configuration consisted of a mid-polar Rxi®-624Sil MS column (30 m × 0.250 mm inner diameter, 1.40 µm film thickness; Restek Corporation, Bellefonte, PA, USA) in the first dimension (^{1}D) and a polar Stabilwax® column (2 m × 0.250 mm inner diameter, 0.50 µm film thickness; Restek Corporation) in the second dimension (^{2}D). A SilTite™ µ-Union (SGE Analytical Science, Wetherill Park, NSW, Australia) was used to connect the ^{1}D and ^{2}D columns. The Rxi®-624Sil MS column is recognised as being highly selective for VOCs. The suitability of the Rxi®-624Sil MS × Stabilwax® column combination has been assessed in a previous study for decomposition VOC profiling [32].

Sample introduction was performed by desorbing the SPME fibre directly in the GC×GC inlet at a temperature of 250 ºC for 5 min using splitless injection with a 30 s inlet purge time. High purity helium (BOC, Sydney, NSW, Australia) was used as the carrier gas at a constant flow rate of 1.0 mL/min. The ^{1}D oven temperature program included a 5 min hold at 35 °C followed by a temperature ramp to 240 ºC at 5 ºC/min before a final hold at 240 ºC for 5 min (i.e. a total run time of 51 min). Relative to the ^{1}D oven, the ^{2}D oven and modulator were programmed to have a constant offset of +15 ºC and +20 ºC, respectively. A modulation period of 5 s was used with a 1.00 s hot pulse time and a 1.50 s cool time between stages. The transfer line connecting the GC×GC with the TOFMS was maintained at 250 °C. The TOFMS detector was operated at a rate of 100 Hz between *m/z* 29 – 450. The ion source temperature was 200 °C and the electron ionisation energy was 70 eV. The detector voltage was set at +200 V above the optimised detector voltage, which was determined daily prior to sample analysis.

2.4. Data Processing

Data processing was performed using ChromaTOF® (version 4.51.6.0; LECO). The baseline was automatically smoothed with an 80% offset. The expected peak widths in the ^{1}D and ^{2}D were set at 30 s and 0.15 s, respectively, based on the typical widths observed for the narrowest, non-saturated peaks within the resultant chromatograms. A minimum signal-to-noise ratio (*S/N*) of 250 was used for

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base peak detection with a minimum of 2 apexing masses and sub-peak detection was cut-off at a minimum *S/N* of 20. A 65% mass spectral match was required to combine subpeaks with each other and their corresponding base peak. Peak identification was performed by a forward search to the 2011 National Institute of Standards and Technology (NIST) mass spectral library database with a minimum similarity match of >80%.

Chromatographic alignment, normalisation and Fisher ratio computation were performed using the Statistical Compare software feature within ChromaTOF® (version 4.51.6.0; LECO). Samples were input into Statistical Compare and separated into two classes: control textiles (n = 21) and experimental textiles (n = 18). During chromatographic alignment, peak researching was performed with a minimum *S/N* cut-off of 20 in order to search for peaks not found during the initial peak finding step. A maximum retention time difference of 10 s (i.e. 2 modulation periods) in the ^{1}D and 0.6 s in the ^{2}D was permitted during alignment to allow for retention time deviations between samples. In order for peaks to be identified as the same compound across chromatograms during alignment a mass spectral match >600 was required. Analytes that did not meet this mass spectral match threshold were removed from the final compound list. In addition, analytes were only retained in the final compound list if detected in at least two or more of the samples within a class. Following alignment, the analyte peak areas (calculated using unique mass) were normalised against the bromobenzene internal standard peak area. Fisher ratio filtering was performed in order to identify class-distinguishing compounds based on its success in previous studies [23,33–38]. Analytes with a Fisher ratio (i.e. the ratio of between-class variance to within-class variance) above the critical value (F_{crit} = 4.11) were exported as a *.csv file and imported into Microsoft Excel for further analysis. The critical value was computed in Microsoft Excel using the F-distribution based on the number of classes in the analysis, the degrees of freedom for each class and the significance level chosen (α = 0.05). Chromatographic artefacts (e.g. column and fibre bleed) were manually removed in Microsoft Excel and the remaining compounds were sorted into one or more of the following chemical classes: alcohol, aldehyde, aromatic, carboxylic acid, ester, ether, halogenated, hydrocarbon, ketone, nitrogen-containing, sulfur-containing or "other" (i.e. compounds with functional groups that did not fit into any of the previously described chemical classes).

Principal component analysis (PCA) was used to view and evaluate the multivariate structure of the data. Data pre-processing (i.e. mean centering, variance scaling and unit vector normalisation [39,40]) was carried out in The Unscrambler® X (version 10.3.31813.89; CAMO Software, Oslo, Norway) followed by PCA. The dataset was verified to contain no outliers by means of the Hotelling's T2 95% confidence limit.

3. Results and Discussion

3.1. Visual Observations

3.1.1 Buried Remains

The pig carcasses buried clothed in 100% cotton t-shirts were exhumed after 1, 3, 6, 12, 18 and 24 months of burial for the observation and collection of textile samples. After one month, when the first pig grave was exhumed, a large amount of soft tissue was present and the entire carcass could be easily extracted as a single, intact specimen. The surrounding soil was very moist, even up to 40 cm above the remains. Three months post-burial the remains of the second pig carcass were exhumed intact with a large amount of soft tissue remaining. Again the surrounding soil was still wet. After lifting the remains, the soil beneath was very dark in colour, appearing almost black. After six months post-burial, the limbs of the pig carcass were fully skeletonized while the soft tissue remaining on the torso had begun to break down and a large presence of white adipocere was observed. The grave exhumed after 12 months contained significant amounts of adipocere, with large tissue sections that were well preserved. The remains after 18 months post-burial were very dry and demonstrated a large amount of tissue loss, with mostly skin and bone remaining. After 24 months, the remains were fully skeletonized and the grave environment was very dry.

3.1.2 Textile Damage

The experimental textile sample exhumed with the first pig carcass after one month burial was very discoloured with orange and brown staining. Large sections of tissue adhered to the surface of the t-shirt and a strong odour was produced. The experimental textile from the grave after three months burial attracted a large amount of flies after it was removed from the grave. After 6 (**Fig. 1a**) and 12 months of burial, the experimental textiles located underneath the pig carcasses were very well preserved. The experimental textile associated with the pig carcass exhumed after 18 months burial had only a small portion of the textile recovered (**Fig. 1b**). This remaining section was found to be well preserved and covered in several layers of tissue, as was observed during the previous exhumations after 6 and 12 months of burial. On the final sampling day, 24 months post-burial, the experimental textile was almost completely disintegrated; however the seams and small sections of textile attached to the seams still remained (**Fig. 1c**).

Fig. 1. Visual damage to the experimental textiles samples exhumed from the pig graves after a) 6, b) 18 and c) 24 months post-burial.

The severe degradation of textile observed in the last two experimental graves (i.e. 18 and 24 months post-burial) was most likely due to the distinct difference in moisture detected during these two post-burial intervals when compared to the other graves. The increased moisture content preserved the remains, especially in the 12 month graves; this was evident by the production of adipocere. It is hypothesised that the presence of remains with soft tissue resulted in the preservation of the experimental cotton samples in these graves.

Control textile samples consisting of 100% cotton t-shirts were exhumed after 1, 3, 6, 12, 18 and 24 months post-burial. The control textile samples were found to degrade rapidly in the soil grave in the absence of any remains and after 12 months there was virtually no part of the t-shirt left other than the seams. The experimental textile samples on the other hand, showed a great deal of preservation suggesting that the presence of decomposing remains prevents the natural bacterial consumption of the cotton fabric. These very distinct visual differences demonstrate another benefit of the use of textiles as training aids. The findings show that textile samples are still likely to be present (and therefore recoverable by scene of crime officers) several years postmortem, even when the remains have skeletonized.

3.2. VOC Profile

The VOC profile of the textile samples was collected using HS-SPME and analysed using GC×GC-TOFMS. **Fig. 2** displays GC×GC-TOFMS total ion current (TIC) contour plots obtained from the control and experimental textiles exhumed and analysed 6 months post-burial. A scale of 0–20% of the normalized signal intensity was required in order to assist with chromatographic visualisation of trace components. These contour plots demonstrate the typical sample complexity and dynamic range observed throughout this study. Overall, an average of 939 analytes were detected from the control textiles and an average of 1116 analytes were detected from the experimental textiles. The overall complexity exhibited in the samples analysed herein continues to support the use of GC×GC-TOFMS for the forensic analysis of decomposition odour.

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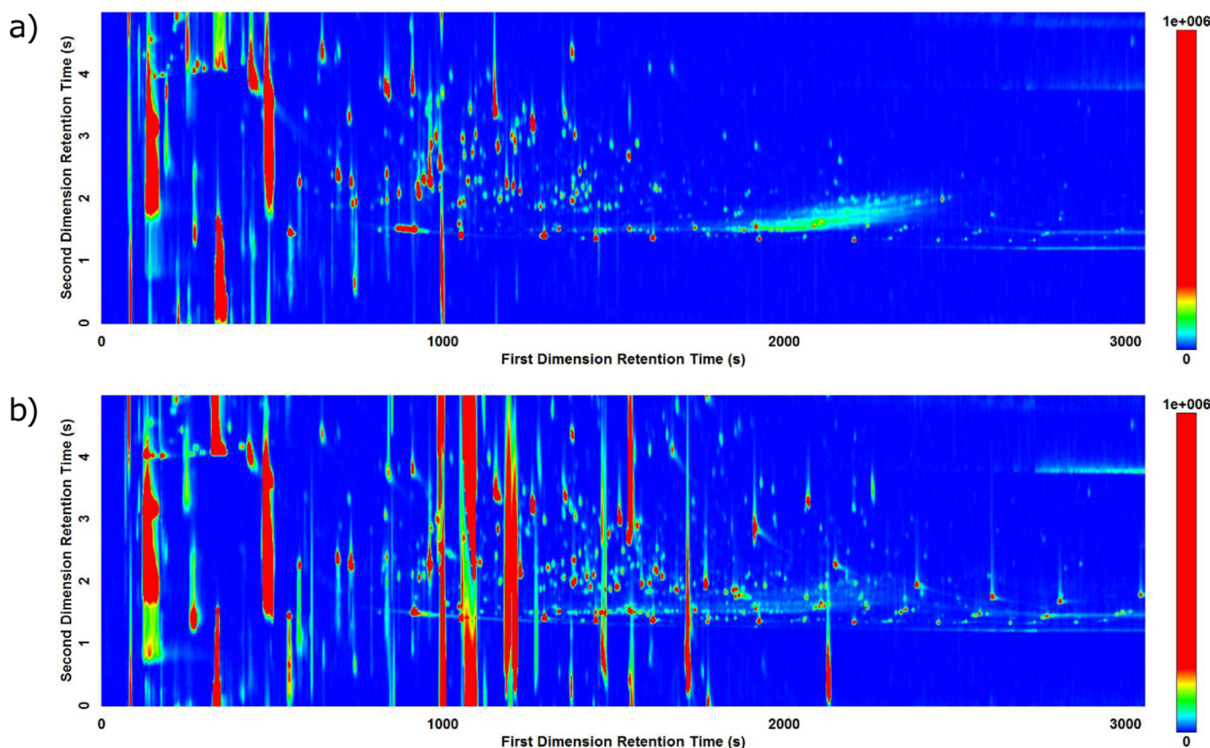

674 **Fig. 2.** GC×GC-TOFMS TIC contour plots of a) control and b) experimental textiles exhumed and
675 analysed 6 months post-burial.
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678 PCA was used to reduce data dimensionality and to provide a visual representation of the multivariate
679 structure of the data using scores and loadings plots. A total of 297 analytes were chosen for
680 submission to PCA. Analytes were chosen using the ChromaTOF® Statistical Compare software
681 feature and Fisher ratio filtering (described in Section 2.4) in order to identify analytes present at
682 significantly different concentrations/levels between the experimental and control textiles. In this case
683 (**Fig. 3**), 43% of the variation within the dataset was captured within the first two principal
684 components. Inspection of additional principal components (i.e. third and fourth principal
685 components) revealed very little variation in the dataset (i.e. 7% and 6%, respectively), and were
686 concluded to provide no further discriminatory information.
687
688 The scores plot (**Fig. 3a**) revealed discrimination between the experimental and control textiles
689 horizontally along the first principal component (PC-1) for the majority of the study period,
690 accounting for 31% of the variation within the dataset. Variation was also observed along PC-1
691 between the experimental textile samples collected at different postmortem intervals and was a result
692 of numerous compounds detected in the profile rather than a few individual VOCs (**Fig. 3b**). While
693 the experimental textile samples were separated horizontally along PC-1, the control textile samples
694 were spread out displaying variation vertically along the second principal component (PC-2) axis,
695 accounting for 12% of the variation within the dataset. This variability in the control textiles is a result
696 of the interaction between the cotton textiles and microorganisms in the burial environment (e.g. fungi
697 and bacteria in the soil) which produce enzymes that are capable of attacking the molecular structure
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of the textile fibre [41,42]. This destruction of the textiles can lead to changes in colour or staining of the textile and unpleasant odours [41,43].

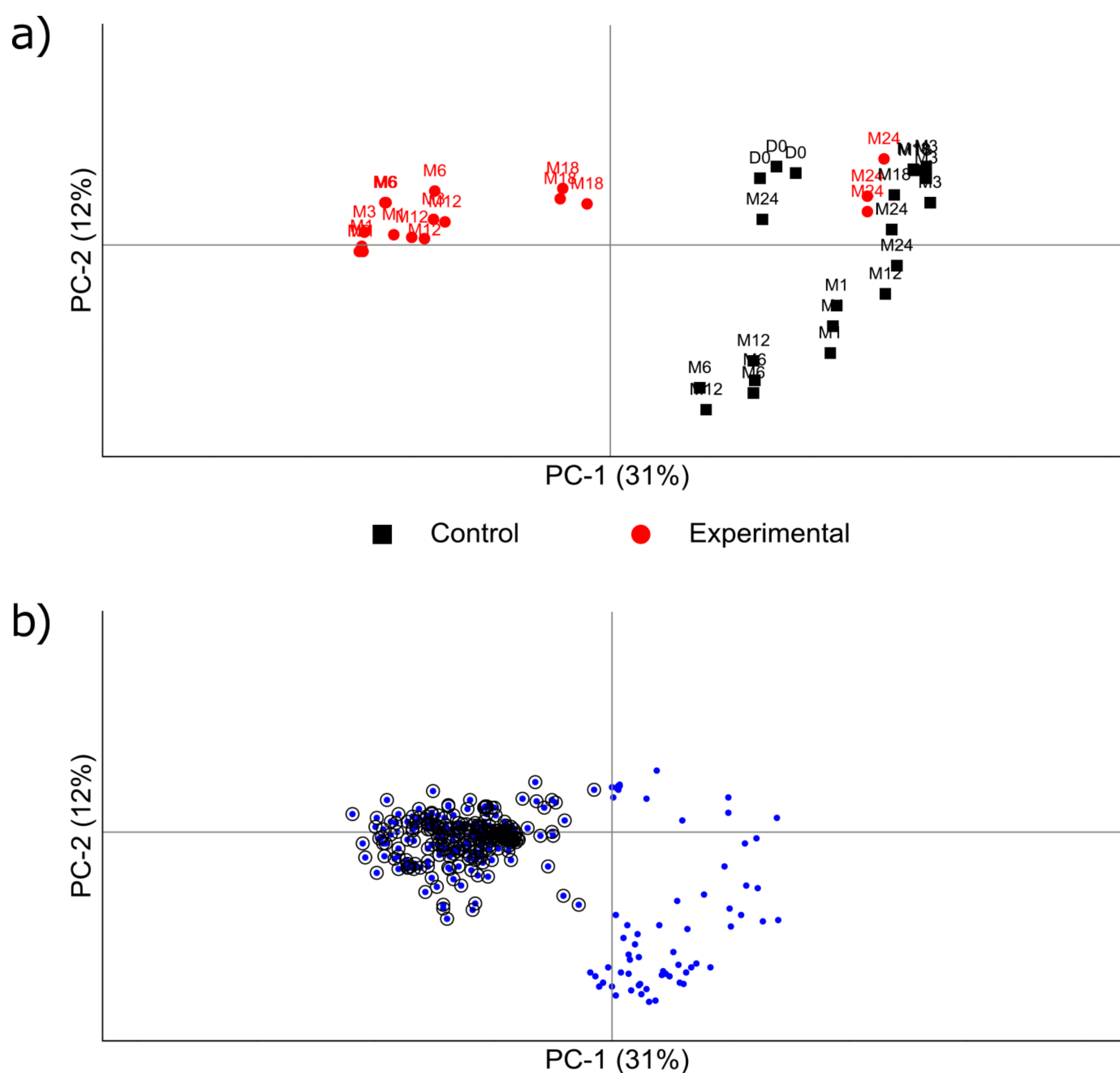

Fig. 3. Principal component analysis (PCA) a) scores and b) loadings plots calculated using pre-processed GC×GC-TOFMS peak area data for compounds detected with a Fisher ratio above F_{crit} in all experimental and control textiles investigated. Point labels in the a) scores plot denote the postmortem interval at the time of exhumation (D = day; M = month). Points circled in the b) loadings plot highlight the detected VOCs (listed in **Table A-1**) that were identified to discriminate the experimental textiles from the control textiles (i.e. *decomposition-related VOCs*).

The VOC profile produced from the experimental textiles collected 24 months postmortem did not appear to be differentiated statistically (**Fig. 3a**) or chromatographically (**Fig. 4**) from the control textiles. The authors recognize the low number of replicates in this study (i.e. $n = 1$ grave per postmortem interval) is a limitation and that the result obtained at 24 months could be an anomaly arising due to differences in decomposition/preservation of both the remains and the textile. As noted

previously, the remains exhumed 24 months post-burial were fully skeletonized and the grave environment was very dry with severe degradation to the textile observed. At this stage of decomposition (i.e. skeletonization) the remains themselves would not be expected to produce an odour as strong as remains that are still actively decomposing (i.e. bloat, active decay and advanced decay stages). Although caution is taken when interpreting these results due to the lack of replicates, it is possible that decomposition odour may not remain trapped within the 100% cotton textiles indefinitely, and that as the postmortem interval increases (and decomposition progresses towards skeletonization) the decomposition odour profile within the textile diminishes. Regardless, these results demonstrate the importance of performing chemical analysis to verify that textiles recovered from remains have retained an odour reflective of cadaveric decomposition before implementing the textile as a training aid in cadaver-detection dog training.

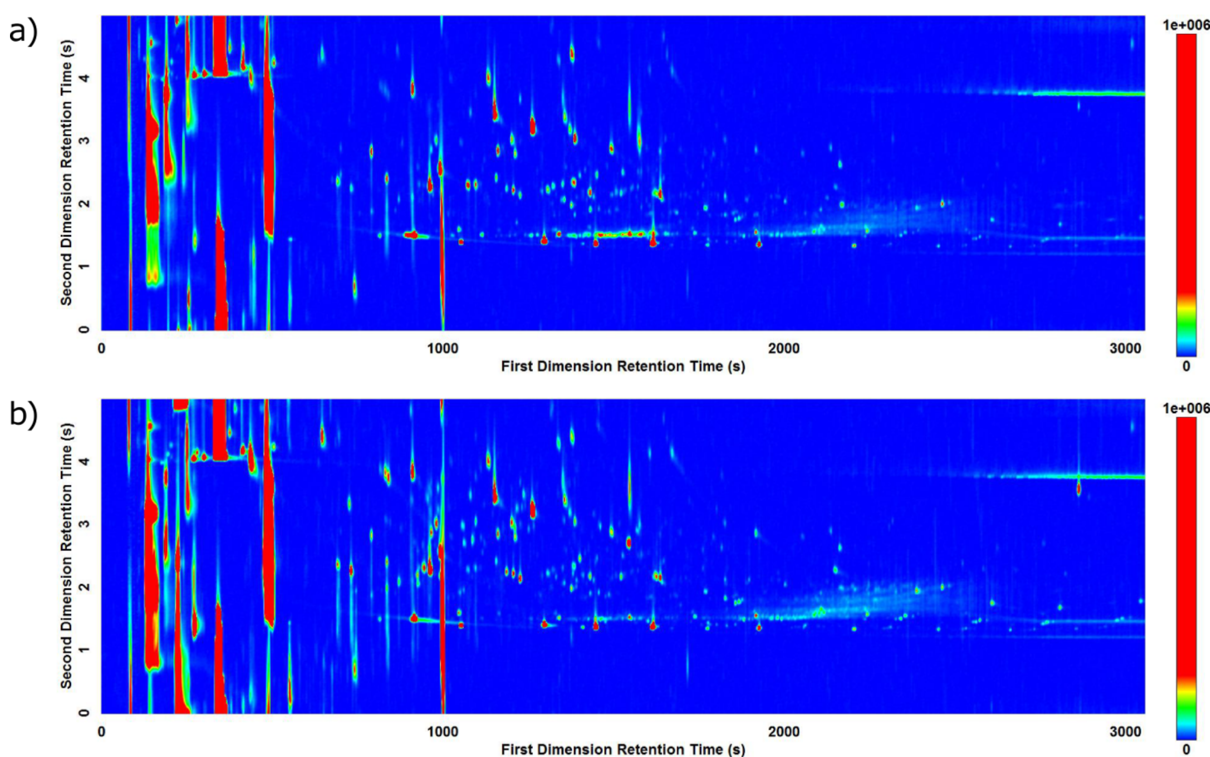

Fig. 4. GC×GC-TOFMS TIC contour plots of a) control and b) experimental textiles exhumed and analysed 24 months post-burial.

Insight into the chemical differences between the control and experimental textiles was gained by examining the loadings plot displayed in **Fig. 3b**. Those analytes that appear grouped in the left-hand quadrants of the loadings plot (**Fig. 3b**) were considered to strongly influence or contribute to the placement of the experimental textile samples in the left-hand quadrants of the scores plot (**Fig. 3a**). Together, these 231 analytes (circled in the loadings plot (**Fig. 3b**) and listed in **Table A-1**) were identified as the VOCs contributing to the discrimination of the experimental textiles from the control textiles and were therefore considered as *decomposition-related VOCs*. More than half (i.e. ~55%) of

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830 these VOCs have been previously identified in at least one other decomposition odour study published
831 in the literature for human remains or human analogues (see **Table A-1**). The remainder of the
832 discussion in this article will focus on these 231 analytes that make up the decomposition odour
833 profile detected in the experimental textiles investigated herein.
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836 **Fig. 5** displays the average VOC abundance ($n = 3$) for all 12 compound classes detected specific to
837 the experimental textiles at each postmortem interval. The overall class composition of the
838 decomposition odour profile was found to change over time and several interesting trends were
839 observed.
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843 The most prominent compound class in the first 12 months of sampling was carboxylic acids. These
844 compounds were detected in very high abundance, often streaking across the GC×GC TIC contour
845 plots (**Fig. 2b** – first dimension retention times of 1000 – 2000 s). The poor peak shapes observed are
846 a result of the high (and often overloaded) concentrations detected and the unfavourable interaction
847 between the GC column stationary phases and the –COOH functional group, which readily forms
848 intermolecular hydrogen bonds [25]. Notably, the carboxylic acid compound class was the only
849 compound class in which all compounds detected were reported in the literature in previous
850 decomposition odour studies (**Table A-1**). Carboxylic acids have previously been identified in fat
851 tissue and adipocere, as well as in muscle tissue [10]. The detection of these compounds may be
852 indicative of the presence of soft tissue on the remains. In the final two graves (18 and 24 months) the
853 abundance of carboxylic acids decreased dramatically, where both of these graves contained remains
854 that were almost void of soft tissue. For improved viewing of trends in other compound classes, **Fig. 5**
855 is also displayed with the carboxylic acid class removed (**Fig. 5b**).
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862 Sulfur-containing compounds (specifically polysulfides) are currently the most widely recognised
863 group of compounds within the decomposition odour profile, as they are the most consistently
864 reported across studies [18,19,44–49]. These sulfur-containing compounds are commonly reported in
865 the earlier stages, especially in the bloat stage [19,45,46]. However, research conducted in the same
866 location as the present study found that polysulfides were detected throughout all decomposition
867 stages in the air above pig carcasses that were allowed to decompose naturally on the soil surface
868 [25]. In the current study, sulfur-containing compounds were not detected as a major contributor to
869 the decomposition odour profile (**Fig. 5b**), rather the sulfur-containing compound class was the least
870 abundant compound class detected at all post-mortem interval investigated (with the exception of
871 ethers, a rarely reported class of decomposition VOCs). Sulfur-containing compounds were detected
872 mostly in the three month samples, at this stage there was a large amount of tissue present, however,
873 the skin had ruptured and the soil beneath the pig was stained black, thus the likelihood of seeing the
874 sulfur-containing compounds were higher than in the one month samples where the pig carcass was
875 fully intact with less purging of fluids into the soil. Beyond three months the remains were in a later
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889 stage of decomposition and the sulfur-containing compounds may have dissipated and diffused
890 through the soil. Although this compound class may be present during all stages of decomposition,
891 sulphur-containing compounds were not detected in great abundance in the textile samples. These
892 compounds might therefore be less retained by the textiles during burial decomposition and might be
893 preferentially retained in the soil instead. Forbes and Perrault [21] found that VOC samples taken
894 from the soil beneath decomposing remains contained a larger number of sulfur-containing
895 compounds than air VOC samples taken above the same remains, again demonstrating the soil's
896 ability to capture and trap these compounds.
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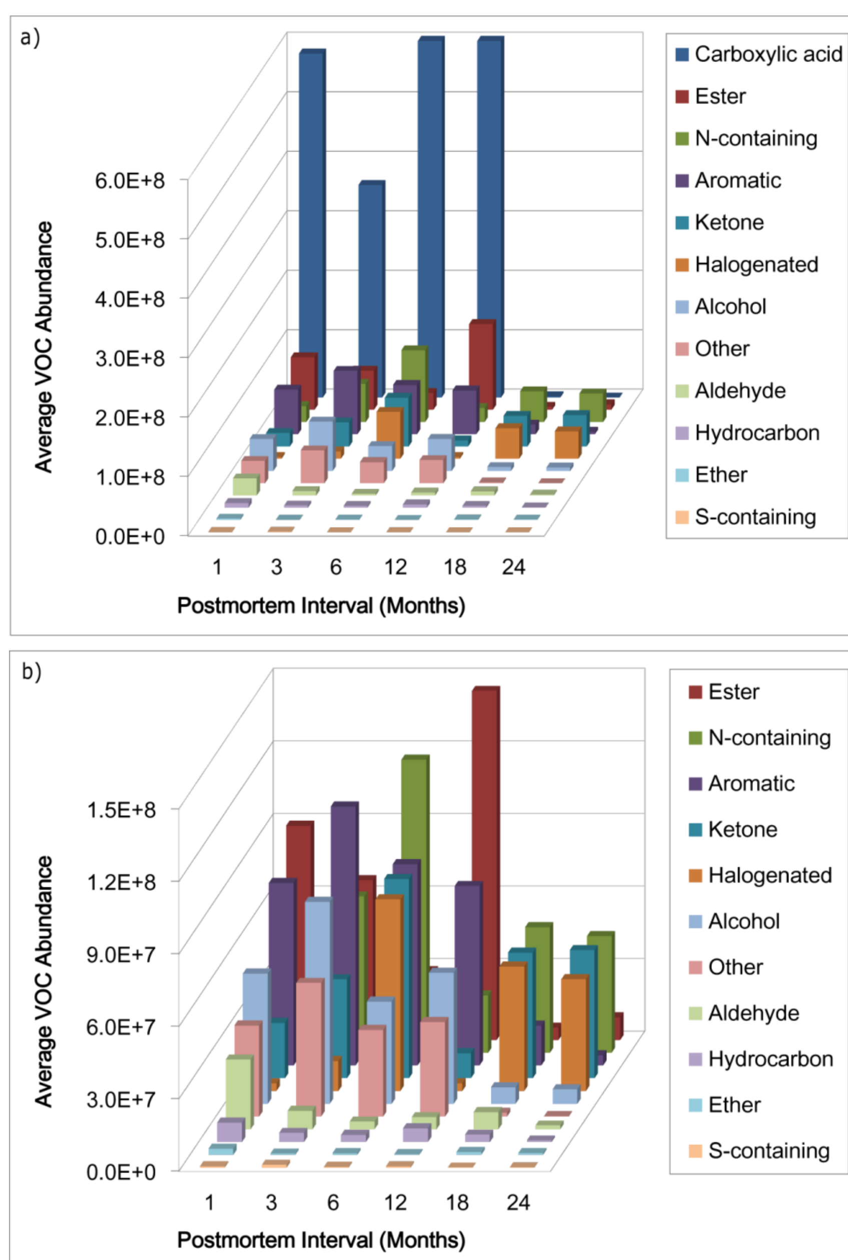
901 

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938 **Fig. 5.** Average VOC abundance ($n = 3$) of compound classes detected specific to the experimental
939 textiles at each postmortem interval a) with and b) without carboxylic acids included for improved
940 viewing of trends in other compound classes. Note VOCs were assigned to multiple classes when
941 necessary (i.e. compounds with multiple functional groups).
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VOCs characterised as esters were initially high before decreasing after the first 6 months. Similar results were reported by Forbes and Perrault [21], who found that when the VOC profile from soil samples was used to distinguish the stages of decomposition, the PCA plot demonstrated that esters were common in the earlier stages of decomposition, and most abundant during active decay. Esters were found to be prevalent in the textile samples when the remains still had a presence of tissue. A large increase in esters was identified in the 12 month samples, which could be due to the presence of adipocere in the grave environment [10]. However, due to the lack of replicate pigs the spike in esters could also be an anomaly and may simply be due to the initial fatty acid content in the pig from that specific gravesite.

Nitrogen-containing compounds were found to increase steadily the first 6 months, before decreasing. This corresponds to other studies where nitrogen-containing VOCs are known to appear in the early stages of decomposition [47].

Aromatic VOCs (especially phenols) have commonly been reported in decomposition VOC studies [18,19,29,46]. The abundance of aromatics was high for the samples collected within the first 12 months and low in the 18 and 24 month samples. These findings correspond to previous research as aromatics are found in the active decay stage and early stages of advanced decay [45,46], the absence of these compounds are then indicative of samples that are from a late stage of decomposition. When looking solely at phenol, it was found in all samples except the 24 month samples (**Table A-1**), which again corresponds to previous findings.

Aldehydes are found more commonly in the later stages of decomposition [18,19,46] and peak during the transition from advanced decay to dry remains for surface studies. However, as the current study involved buried specimens, which tends to promote the formation of adipocere [50], it is more likely that the presence of aldehydes would be less significant as these are formed in aerobic conditions. The one month post-burial grave was disturbed by scavengers on day 2 after burial, which resulted in the remains being exposed. However, the remains were covered again and wire mesh was added to avoid further burrowing. This soil disturbance likely introduced air in the grave. Maggots were also found upon excavation and this might explain the presence of aldehydes in the one month textile samples as some aerobic decomposition was likely to have occurred. The remaining sampling months had a relatively consistent and low abundance of aldehydes.

Ethers are a rarely reported class of decomposition VOCs [51], which is consistent with the low number and abundance of ethers detected at all postmortem intervals investigated throughout this study. Hydrocarbons were most abundant in the samples collected 1 month post-burial, before decreasing and remaining fairly stable. Ketones were found to increase for the first 6 months before a decrease was seen in the 12 month samples; the abundance of ketones then increased and remained

consistent for the last two excavation times. There was a spike in halogenated compounds detected in the 6 month post-burial samples, and a higher amount in the 18 and 24 month samples compared to the other sampling days. Lastly, alcohols were determined to be higher in abundance in samples where soft tissue was still present, similarly to aromatic compounds, carboxylic acids, esters and aromatics.

Overall, there was a lack of sulfur-containing compounds detected in the textile samples; however, this may be due to the fact that the remains were buried in a soil environment rather than being placed on the soil surface during decomposition. Despite the reduced amount of sulphur-containing compounds detected, the remaining compound classes commonly reported in decomposition odour research (i.e. carboxylic acids, esters, nitrogen-containing compounds and aromatics) all produced VOC profiles from the textile samples that were consistent with that of decomposing remains. This demonstrates the ability of textiles to retain an odour comparable to that of decomposing remains and suggests that although the profile may not be retained indefinitely, as determined by the PCA analysis (**Fig. 3a**), textiles could be a viable option as a training aid for cadaver-detection dogs.

4. Conclusions

This study provides evidence that 100% cotton textiles associated with decomposing remains may represent a useful natural training aid for cadaver-detection dogs with a VOC profile reflective of a large subset of cadaveric decomposition odour. Obtaining textiles associated with decomposing remains from different postmortem intervals is useful for providing training aids that represent the broad spectrum of decomposition odour cadaver-detection dogs are likely to encounter in the field when searching for remains at varying stages of decomposition. Results suggest that decomposition odour may not remain trapped in the 100% cotton textile indefinitely, and therefore chemical analysis is valuable for the verification that textiles recovered from remains have retained an odour reflective of cadaveric decomposition before the textiles are employed as a training aid. Chemical analysis could likewise prove useful in confirming that the odour is retained overtime with prolonged use and storage.

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Appendix A.

Table A-1
List of tentatively identified decomposition VOCs detected (×) in the experimental textiles grouped according to compound class. Literature references are provided for compounds that have been previously reported in decomposition odour research. Note: each VOC only appears once in the table (i.e. assigned to a single compound class); however, for the purposes of overall analysis, VOCs were assigned to multiple compound classes when necessary (i.e. compounds with multiple functional groups).

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
Alcohol							
1,5-Hexadien-3-ol	×	×	×	×	×	×	[22,51]
1-Heptanol	×	×	×	×	×	×	[18,19,30,51–53]
1-Hexanol	×	×	×	×	×		[10,18,19,22,28,47,49,51,52,54–56]
1-Octanol	×	×	×	×	×	×	[10,18,19,21,29,30,51,52,56]
1-Octen-3-ol	×	×	×	×	×	×	[10,19,47,51–53,56]
1-Pentanol			×			×	[3,10,18,19,21,22,28,30,46,47,51,52,54,55]
2-Octanol, (S)-	×	×	×	×	×	×	
2-Pentanol				×			[21,22,30,32,47,51–53,55,57]
2-Propanol, 2-methyl-		×	×	×	×	×	
3-Octanol	×	×	×	×	×	×	
Isoborneol	×	×	×	×	×	×	[29]
Aldehyde							
(E)-4-Oxohex-2-enal	×	×	×		×		
2,4-Nonadienal, (E,E)-	×				×		[10,28]
2-Butenal, 2-ethenyl-	×		×				
2-Butenal, 3-methyl-	×	×	×	×	×	×	[18,51,52]
2-Heptenal, (Z)-	×	×	×	×	×	×	[10,19,22,28,51]
2-Nonenal, (E)-	×	×	×	×	×	×	[10,18,28,51]
2-Octenal, (E)-	×	×	×	×	×	×	[10,18,19,28,51]
2-Pentenal, (E)-	×	×	×	×	×	×	[47]
2-n-Butylacrolein	×	×	×	×	×	×	[22,38,51]
Decanal	×	×	×	×	×	×	[28,29,44,49,51]
Heptanal	×	×	×	×	×	×	[3,18,19,28,30,46,51–53,56,58]
Nonanal	×	×	×	×	×	×	[10,18,21,22,28–30,44,49,51,52,58]

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
Octanal	×	×	×	×	×	×	[10,18,19,21,28,30,51,52,56,58]
Pentanal	×	×	×	×	×	×	[19,38,46,51,52,54,58]
Aromatic							
2-(5-Methyl-furan-2-yl)-propionaldehyde					×		
2-Ethylhexyl salicylate	×	×	×	×	×	×	
2-Heptylfuran	×	×	×	×	×	×	[30]
3-Phenylpropanol	×	×	×	×	×		
Acetic acid, 2-phenylethyl ester	×	×	×	×			
Acetophenone	×	×	×	×	×	×	[32,47,48,51]
Benzaldehyde	×	×	×	×	×	×	[3,10,18,19,28–30,32,44,46–48,51–53,55,56]
Benzene, (1,1-dimethylethoxy)-	×	×	×	×	×		
Benzene, (1-methylethyl)-	×	×	×	×	×	×	[18]
Benzene, 1,2,3,4-tetramethyl-	×	×	×	×	×	×	[29,57]
Benzene, 1,2,3-trimethyl-	×	×	×	×	×	×	[29,52,54,59]
Benzene, 1,2,4,5-tetramethyl-	×	×	×	×	×	×	
Benzene, 1,3,5-trimethoxy-	×	×	×	×	×	×	
Benzene, 1,3-dichloro-	×	×	×	×	×	×	
Benzene, 1,3-diethyl-	×	×	×	×	×	×	
Benzene, 1,3-dimethyl-	×	×	×	×	×	×	[52,55]
Benzene, 1-ethenyl-4-ethyl-	×	×	×	×	×	×	
Benzene, 1-ethyl-2-methyl-	×	×	×	×	×	×	[38,49,57,58]
Benzene, 1-ethyl-3-methyl-	×	×	×	×	×	×	[47,57]
Benzene, 1-methoxy-4-methyl-	×	×	×	×	×	×	[48]
Benzene, 1-methyl-3-(1-methylethyl)-	×	×	×	×	×	×	[32,51,52,55,57]
Benzene, 1-methyl-3-propyl-	×	×	×	×	×	×	
Benzene, 1-methyl-4-(1-methylpropyl)-	×	×	×	×	×	×	
Benzene, 1-methyl-4-propyl-	×	×	×	×	×	×	[57]
Benzene, 2-ethyl-1,3-dimethyl-	×	×	×	×	×	×	
Benzene, 4-ethyl-1,2-dimethyl-	×	×	×	×	×	×	
Benzene, hexyl-	×	×	×	×	×	×	
Benzene, pentyl-	×	×	×	×	×	×	[38]
Benzene, propyl-	×	×	×	×	×	×	[32,38,47,52,54,55]
Benzeneethanol, à-methyl-	×	×	×	×	×		

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
Benzenemethanol, à,à-dimethyl-							[23,44,49,58]
Benzenemethanol, à-methyl-, (R)-	×	×	×	×	×		[18]
Benzenepropanal, á-methyl-	×	×	×	×	×	×	
Benzenepropanoic acid, methyl ester	×	×	×	×	×	×	
Furan, 2-pentyl-	×	×	×	×	×	×	[3,10,18,21,28,30,32,51,52,55]
Furan, 2-propyl-	×			×	×		[38,55]
Furfural	×	×	×	×	×	×	[29]
Indan, 1-methyl-	×	×	×	×	×	×	
Indane	×	×	×	×	×	×	[54]
Naphthalene, 1,2,3,4-tetrahydro-	×	×	×	×	×	×	
Oxirane, 2-methyl-2-phenyl-	×	×	×	×	×	×	
Phenol	×	×	×	×	×		[19,21,29,30,46–48,51–53,55,56,59]
Phenol, 2,4-bis(1,1-dimethylethyl)-	×	×	×	×	×	×	
Phosphonic acid, (p-hydroxyphenyl)-	×	×	×	×	×	×	
Propanoic acid, 2-methyl-, 3-phenylpropyl ester	×	×	×	×			
Propanoic acid, 2-phenylethyl ester	×	×	×	×			
o-Cymene	×	×	×	×	×	×	[51,52]
o-Xylene	×	×	×	×	×	×	[18,29,38,47,51,55,59]
p-Cresol	×	×	×	×	×	×	[22,51]
p-Cymene	×	×	×	×	×	×	[18,46]
á-Phenylethyl butyrate	×	×	×	×			
Carboxylic acid							
Acetic acid	×	×	×	×			[19,21,29,30,47,51,53,56]
Butanoic acid	×	×	×	×	×		[3,10,18,19,21,22,30,46,51,53,56]
Butanoic acid, 2-methyl-	×	×	×	×	×		[18,19,21,22,28–30,46,51,53]
Butanoic acid, 3-methyl-	×	×	×	×	×		[18,19,21,22,28,30,46,51,53]
Hexanoic acid	×		×	×			[3,10,18,19,28–30,32,46,51,56]
Propanoic acid	×	×	×	×			[3,10,19,21,22,28,30,46,51,53,56]
Propanoic acid, 2-methyl-	×	×	×	×	×		[18,19,21,22,29,30,46,51,56]
Ester							
1,3-Propanediol, diacetate	×	×	×				
1-Butanol, 3-methyl-, propanoate	×	×	×	×	×		
2(3H)-Furanone, 5-ethyldihydro-	×	×	×	×	×	×	[38]

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
2(3H)-Furanone, 5-hexyldihydro-	×	×	×	×			
2(3H)-Furanone, dihydro-	×	×	×	×	×	×	[56]
2(3H)-Furanone, dihydro-5-methyl-	×	×	×	×	×	×	[18]
2(3H)-Furanone, dihydro-5-pentyl-	×	×	×	×	×		
2(3H)-Furanone, dihydro-5-propyl-	×	×	×	×	×		[38]
Acetic acid, methyl ester	×	×	×	×	×	×	[22,30,32,51,52,55]
Acetic acid, pentyl ester	×	×	×	×			[38]
Butanoic acid, 1-methyl-, butyl ester	×	×	×	×	×	×	
Butanoic acid, 2-methyl-, hexyl ester	×	×	×	×	×	×	
Butanoic acid, 3-methyl-, butyl ester	×	×	×	×	×	×	[18,21,30]
Butanoic acid, 3-methyl-, hexyl ester	×	×	×	×	×	×	
Butanoic acid, 3-methyl-, pentyl ester	×	×	×	×	×	×	
Butanoic acid, hexyl ester	×	×	×	×	×	×	[30]
Butanoic acid, methyl ester	×	×	×	×	×	×	[21,28,30,32,51,52,55]
Butanoic acid, pentyl ester	×	×	×	×	×	×	[30]
Decanoic acid, ethyl ester	×	×		×			
Heptanoic acid, methyl ester	×	×	×	×	×	×	[30]
Hexanoic acid, 1-methyl-, ethyl ester	×		×	×			
Hexanoic acid, 2-methyl-, propyl ester	×	×	×	×			
Hexanoic acid, ethyl ester	×	×	×	×	×	×	[10,28,30]
Hexanoic acid, hexyl ester	×		×	×			[10,28]
Hexanoic acid, ethenyl ester	×						
Hexanoic acid, methyl ester	×	×	×	×	×	×	[28,30]
Hexanoic acid, pentyl ester	×	×	×	×			[10,28,30]
Octanoic acid, methyl ester	×	×	×	×	×	×	[28,30]
Pentanoic acid, ethyl ester	×	×	×	×	×	×	[21,30]
Pentanoic acid, methyl ester	×	×	×	×	×	×	[30]
Propanoic acid, 2,2-dimethyl-, 2-phenylethyl ester	×	×	×	×			
Propanoic acid, 2-methyl-, pentyl ester	×	×	×	×	×	×	
Propanoic acid, butyl ester	×	×	×	×	×		[18]
Propanoic acid, heptyl ester	×	×	×	×	×	×	
Propanoic acid, hexyl ester	×	×	×	×	×	×	
Propanoic acid, methyl ester	×	×	×	×	×	×	[32,51,52,55]

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
Ether							
Furan, 2,3-dihydro-2,5-dimethyl-		×	×	×	×	×	[18]
Furan, 2-butyltetrahydro-	×	×	×				[18,21,30,52]
Oxirane, ethyl-	×		×		×	×	
Oxirane, hexyl-	×	×	×	×	×	×	
Halogenated							
Ethane, hexachloro-	×	×	×	×	×	×	
Pentane, 3-bromo-3-methyl-	×	×				×	
Tetrachloroethylene	×	×	×	×	×	×	[10,28,44,49,58]
Hydrocarbon							
1,3-Heptadiene, 5,5-dimethyl-	×	×	×	×	×	×	
5-Undecene, (E)-	×	×	×	×	×	×	
5-Undecene, (Z)-	×	×	×	×	×	×	
3-Dodecene, (Z)-	×	×	×	×	×	×	
1-Nonene	×	×	×	×	×	×	
8-Heptadecene	×	×	×	×	×	×	[21,30,51,52]
Aromandendrene	×	×	×	×	×	×	[22,52]
Bicyclo[7.2.0]undec-4-ene, 4,11,11-trimethyl-8-methylene-,[1R-(1R*,4Z,9S*)]-	×	×	×	×	×	×	
Cyclohexane, (2-ethyl-1-methylbutylidene)-	×	×	×	×	×	×	
Cyclohexane, butyl-	×	×	×	×	×	×	
Cyclohexane, hexyl-	×	×	×	×	×	×	
Cyclohexane, propyl-	×		×	×	×	×	[51,57]
Cyclohexene, 1-methyl-4-(1-methylethenyl)-, (S)-	×	×	×	×	×	×	[51,53]
Cyclohexene, 4-ethenyl-4-methyl-3-(1-methylethenyl)-1-(1-methylethyl)-, (3R-trans)-				×	×	×	
Decane	×	×	×	×		×	[28,38,47,53,57–59]
Decane, 2,3,5,8-tetramethyl-	×	×	×	×	×	×	
Decane, 2,4,6-trimethyl-	×	×	×	×	×	×	[57]
Decane, 2,6-dimethyl	×	×	×	×	×	×	
Decane, 4-methyl-	×	×	×	×	×	×	
Decane, 5-methyl-	×	×	×	×	×	×	
Dodecane	×	×	×	×	×	×	[18,28,47,51]

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
Dodecane, 2,7,10-trimethyl-	×	×	×	×	×	×	
Heptadecane	×	×	×	×	×	×	[29,30,51–53]
Nonane	×	×	×	×	×	×	[18,19,23,47,51–53,55,58]
Nonane, 2-methyl-	×	×	×	×	×	×	[57]
Nonane, 3-methyl-	×	×	×	×	×	×	[38,47]
Octane, 3-ethyl-	×	×	×	×	×	×	
Undecane	×	×	×	×	×	×	[18,28,29,44,49,51–53,55,57–59]
Undecane, 2,6-dimethyl-	×	×	×	×	×	×	[46,57]
Undecane, 2-methyl-	×	×	×	×	×	×	[47]
Undecane, 3-methyl-	×	×	×	×	×	×	[47]
Undecane, 4-methyl-	×	×	×	×	×	×	
á-Pinene	×	×	×	×	×	×	[18,21,22,30,32,47,51,52,54,55]
Ketone							
2,3-Pentanedione	×	×	×	×	×	×	[22,51,52]
2,5-Hexanedione		×	×	×	×	×	[18]
2-Decanone	×	×	×	×	×	×	[18,19,28,30,51]
2-Tridecanone	×	×	×	×	×	×	[48,53]
2-Dodecanone	×	×	×	×	×	×	
2-Nonadecanone	×	×	×	×	×		[21,30]
2-Nonanone	×	×	×	×	×	×	[18,19,21,28,30,46,48,51–53,59]
2-Pentanone, 4-hydroxy-4-methyl-	×	×	×	×	×	×	[51,57]
2-Tetradecanone	×	×	×	×	×		[51]
3,4-Hexanedione	×		×				
3,5-Octadien-2-one, (E,E)-	×	×	×	×	×	×	[28,30]
3-Hepten-2-one, 5-methyl-	×	×	×	×	×	×	
3-Nonen-2-one	×	×	×	×	×	×	
3-Octen-2-one	×	×	×	×	×	×	[19,30,51]
3-Penten-2-one, (E)-	×	×	×	×	×	×	[46]
4-Penten-2-one, 4-methyl-	×	×					[18]
Ethanone, 1-(3-butyloxiranyl)-	×	×	×	×	×	×	
N-containing							
1-Butanamine		×	×				
1-Butanamine, 3-methyl-N-(2-phenylethylidene)-	×	×	×				

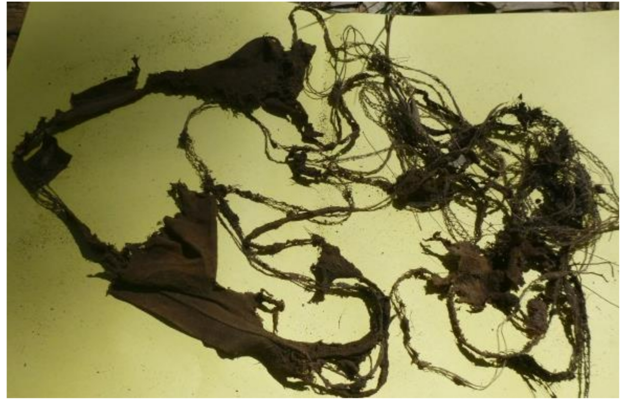
Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
1-Butanamine, 3-methyl-N-(3-methylbutylidene)-		×	×				[51]
1-Butanol, 3-methyl-, nitrate	×	×	×	×	×		
1H-Indole, 3-methyl-		×	×	×	×	×	[18,19,53]
1H-Pyrrole, 1-methyl-	×	×	×				[51]
1H-Pyrrole, 2,4-dimethyl-		×	×		×	×	
1H-Pyrrole, 2,5-dimethyl-	×	×	×	×			[18,51]
1H-Pyrrole-2,5-dione, 1-methyl-	×						
1H-Pyrrole-2-carboxaldehyde, 1-methyl-	×	×	×				
2-Piperidinone	×	×	×	×			[18,21,30,46,51]
2-Pyrrolidineethanol, 1-methyl-	×						
5H-1-Pyrindine	×	×	×	×	×	×	[22,52]
8-Azabicyclo[3.2.1]oct-6-en-3-one, 8-methyl-	×	×	×				
Acetamide	×	×	×	×			[18,46]
Acetamide, 2,2,2-trifluoro-		×	×	×	×	×	
Acetamide, 2,2,2-trifluoro-N-(2-methylpropyl)-		×	×		×		
Acetamide, 2,2,2-trifluoro-N-(2-phenylethyl)-		×	×		×		
Acetamide, 2,2,2-trifluoro-N-propyl-			×				
Acetamide, N-(3-methylbutyl)-	×	×	×	×	×		
Acetamide, N-butyl-2,2,2-trifluoro-		×	×		×		
Amantadine	×	×	×				
Benzonitrile	×	×	×	×	×	×	[19,21–23,29,30,32,44,46,48,51–53,55]
Butanamide	×	×	×				[18,46,51]
Butanamide, 3-methyl-	×	×	×	×			[18,46,51]
Cyclohexanone, 3-methyl-	×	×	×		×	×	[48,51,52,55]
Hexanamide	×	×	×	×			[18]
Hexane, 1-nitro-	×	×	×	×	×	×	
Indole	×	×	×	×	×		[10,18,19,21,28,30,46,48,51–53,56,60]
Methanamine, N-heptylidene-	×	×	×				
Methylamine, N,N-dimethyl-	×	×	×	×	×	×	[22,51,52,57]
Pentanal, oxime	×	×	×	×			
Propanamide	×	×	×				[18,46]
Propanamide, 2-methyl-	×	×	×				[18]
Propanamide, N,2-dimethyl-	×	×	×		×		[18]

Volatile Organic Compounds (VOCs)	Postmortem Interval (Months)						Literature References
	1	3	6	12	18	24	
Propanamide, N-hexyl-	×	×	×	×	×		
Propanamide, N-methyl-		×	×				[18,46]
Pyrazine, tetramethyl-	×	×	×	×	×	×	[18,53,56]
Pyrazine, trimethyl-	×	×	×	×	×	×	[18,28,46,51]
Pyridine, 2-methyl-	×	×	×	×	×	×	[18,51,52]
Pyridine, 2-pentyl-	×	×	×	×			
Pyridine, 2-methyl-6-propyl-	×	×	×	×			
Pyridine, 3-butyl-	×	×	×				
Pyridine, 3-ethyl-	×	×					
Pyridine, 3-propyl-	×	×					
Pyrrole, 1,2,5-trimethyl-		×	×				
S-containing							
2-Furanmethanethiol, 5-methyl-	×	×			×		
3-(Methylthio)propanoic acid methyl ester		×	×	×			
Dimethyl sulfone	×	×					[22,38,47,51,57]
Disulfide, methyl pentyl	×	×	×	×	×		[53]
Isothiocyanate , 2,5-dimethylphenyl	×	×	×		×		
Methanethiol	×	×	×	×	×	×	[22,46,47,51–53,57,60]
Pentane, 1-(methylthio)-	×	×		×			[51]
Sulfurous acid, isobutyl pentyl ester	×		×				
Thiophene, 2-pentyl-	×	×	×	×	×	×	[51,52]

a)

b)

c)



a)

Second Dimension Retention Time (s)

0 1 2 3 4

0 1000 2000 3000

First Dimension Retention Time (s)

1e+006

0

b)

Second Dimension Retention Time (s)

0 1 2 3 4

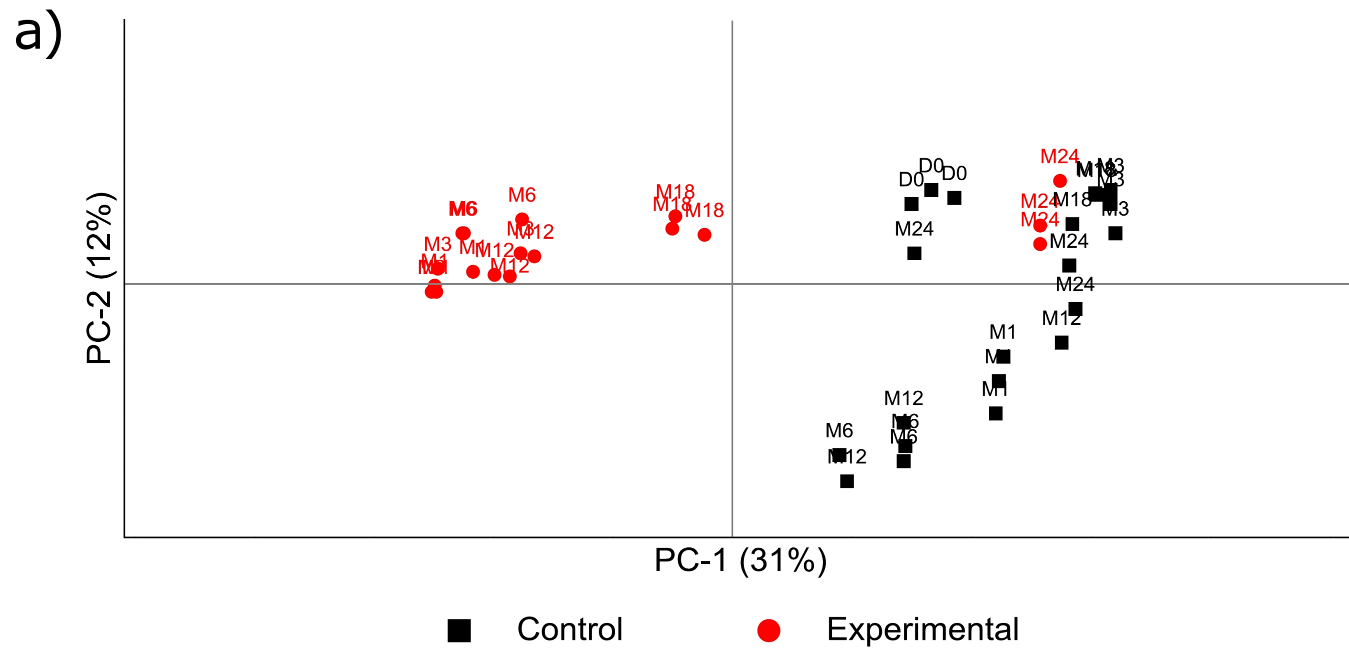
0 1000 2000 3000

First Dimension Retention Time (s)

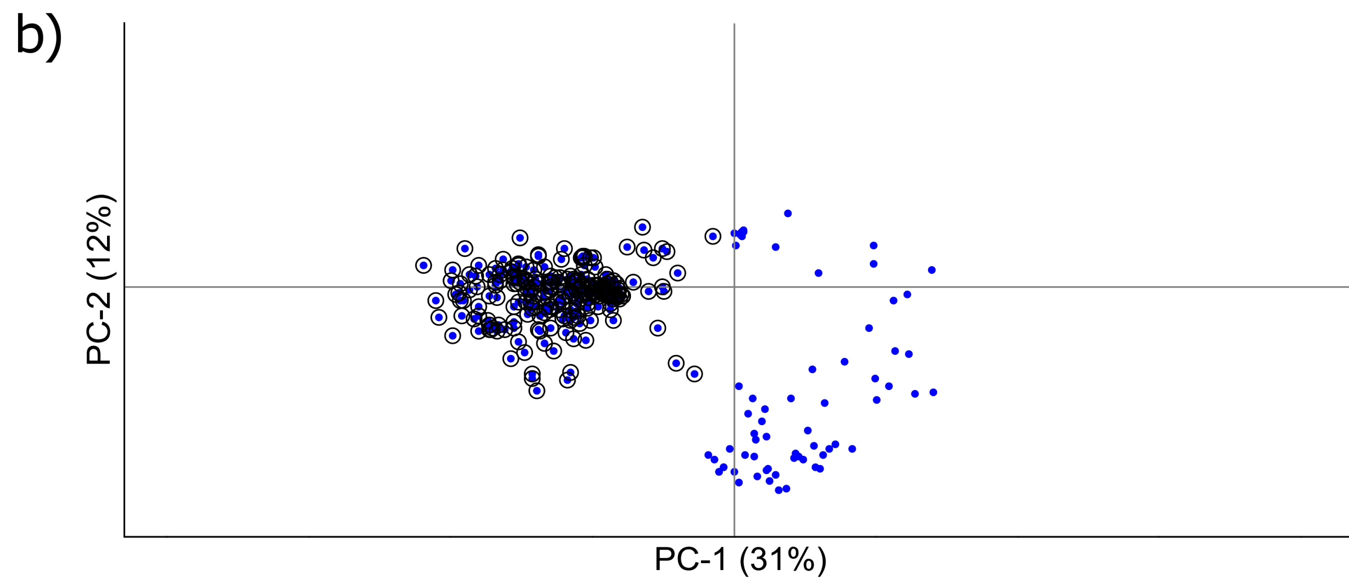
1e+006

0

a)



b)



a)

Second Dimension Retention Time (s)

0 1 2 3 4

0 1000 2000 3000

First Dimension Retention Time (s)

1e+006

0

b)

Second Dimension Retention Time (s)

0 1 2 3 4

0 1000 2000 3000

First Dimension Retention Time (s)

1e+006

0

a)

Average VOC Abundance

6.0E+8
5.0E+8
4.0E+8
3.0E+8
2.0E+8
1.0E+8
0.0E+0

1 3 6 12 18 24

Postmortem Interval (Months)

Carboxylic acid
Ester
N-containing
Aromatic
Ketone
Halogenated
Alcohol
Other
Aldehyde
Hydrocarbon
Ether
S-containing

b)

Average VOC Abundance

1.5E+8
1.2E+8
9.0E+7
6.0E+7
3.0E+7
0.0E+0

1 3 6 12 18 24

Postmortem Interval (Months)

Ester
N-containing
Aromatic
Ketone
Halogenated
Alcohol
Other
Aldehyde
Hydrocarbon
Ether
S-containing

Highlights:

- Odour profiles of textiles associated with decomposing remains were investigated
- Pig carcasses clothed in 100% cotton t-shirts were used as human odour analogues
- Textiles collected at different postmortem intervals exhibited variation in odour
- Overall odour profile reflected a large subset of cadaveric decomposition odour
- Results suggest decomposition odour may not remain trapped in textile indefinitely