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Coumarins as turn on/off fluorescent probes for detection of residual acetone in cosmetics following headspace single-drop microextraction

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ABSTRACT

In this work, a new method based on headspace-single drop microextraction for the determination of residual acetone in cosmetics by microfluorospectrometry is proposed. Acetone causes fluorescence changes in a 2.5 μL-ethanolic drop (40% v/v) containing 3.10^{-4} mol L^{-1} 7-hydroxy-4-methylcoumarin ('turn off') or 6.10^{-6} mol L^{-1} 7-diethylamino-4-methylcoumarin ('turn on'). Polarity and ability to form hydrogen bonds of short chain alcohols (polar protic solvents) were crucial in order to observe these changes in the presence of acetone (polar aprotic solvent). Parameters related with the HS-SDME procedure were studied, namely headspace volume, composition, volume and temperature of drop, microextraction time, stirring rate, mass and temperature of sample, as well as the effect of potential interferents (alcohols and fragrances). The high volatility of acetone allows its extraction from an untreated cosmetic sample within 3 min. A detection limit of 0.26 μg g^{-1} and repeatability, expressed as relative standard deviation, around 5% were reached. Accuracy of the proposed methodology was evaluated by means of recovery studies. The method was successfully used to analyze different cosmetics. Simplicity and high sample throughput can be highlighted.

1. Introduction

In last years, new ingredients have been gradually introduced into cosmetic formulations. The scarce solubility of many of them (*e.g.,* polymers as nitrocellulose or cellulose acetate butyrate) makes it essential the use of different solvents as ethanol, glycerin, propylene glycol, acetone, *etc.* [1]. Although different processes are intended to remove these solvents from the final formulation, traces of them are likely to remain in the commercial product [2].

Particularly, acetone is used in cosmetics as solvent and denaturant, thus being found at trace level or even at high concentration. Apart from nail polishes, other cosmetics such as bath, cleansing, hair care or skin care products may contain residual amounts of acetone. Thus, Zhao et al. [3] found residual acetone in 7 of 10 skin-care and cleaning cosmetics (concentrations between 6.5 and 211.9 ppm).

Since acetone can be considered as a potential risk for consumers even at these levels (*i.e.,* it is a defatting agent to the skin and an eye irritant) [4], the control of this solvent in commercial formulations becomes essential. In spite of that, no official analytical methods have been established to this end, and in addition, few papers have been published on this issue [3,5,6]. In general, tedious and time-consuming sample treatments involving high volumes of reagents are common in these procedures.

In last years, new methods based on the benefits of microextraction techniques have been developed for cosmetic analysis. In special, the headspace-single drop microextraction (HS-SDME) mode may provide the following benefits: (i) a scarce sample clean-up is required, *i.e.,* only dispersion of cosmetic in water [7] or ethanol [8]; (ii) direct elimination of non-volatile interferences occurs; (iii) there is the possibility of using aqueous extractant phases, *e.g.,* an aqueous drop containing alcohol dehydrogenase and β-NAD was used as extractant and fluorescence probe for ethanol determination in cosmetics [7]; (iv) a dramatic decrease in extractant volume is achieved, *e.g.*, 2.5 μL can be used in accordance with the detection technique as microvolume spectrophotometry [9] or microvolume fluorospectrometry [7,8], and (v) the use of 'natural' reagents in the drop emphasizes the green character of microextraction procedures [7,8].

In this regard, coumarins are metabolites from some higher plants [10] that are fluorophores with interesting applications as chemical probes [11]. On the one hand, their fluorescence properties are highly dependent of the position and nature of chemical substituents, *e.g.*, 3 and 4-substituted hydroxicoumarins emit in the UV region, while 5, 6 and 7-hydroxicoumarins do it in the visible region [12]. On the other hand, fluorescence of coumarins is very sensitive to changes in the medium, in special polarity, pH and viscosity. These changes can modify excitation an emission

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spectra, resulting in fluorescence 'turn on' or 'turn off' of coumarins [13]. This effect has been directly observed for some organic solvents, among them, acetone [12,14,15].

Bearing in mind the volatility of acetone and its possible effect on the fluorescence of coumarins, a new method for the determination of residual acetone in cosmetics using a HS-SDME procedure with a drop containing a coumarin (7-hydroxy-4-methylcoumarin or 7-diethylamino-4-methylcoumarin) in an ethanol–water mixture is described. A microvolume fluorospectrometer was used for monitoring fluorescence changes caused by acetone in the drop. No pretreatment of cosmetic samples was required.

2. Experimental

2.1. Apparatus

A Thermo Scientific NanoDrop 3300 Fluorospectrometer (Thermo, Wilmington, USA) was used for measuring fluorescence changes. A UV Light Emitting Diode at 365 nm was used as excitation source in all cases. Emission measurements were made at 443 and 460 nm for 7-hydroxy-4-methylcoumarin and 7-diethylamino-4-methylcoumarin, respectively.

A 10-μL Hamilton syringe (Hamilton Company, Nevada, USA) with a guided-PTFE plunger was used for microextraction. Vials of different volume (between 0.5 and 40 mL) with a silicone rubber septum were used.

High-purity deionised water was obtained from a PETLAB ultrapure water system (Peter Taboada, Vigo, Spain).

2.2. Reagents and samples

Acetone analytical standard was obtained from Sigma-Aldrich (Steinheim, Germany). 7-hydroxy-4-methylcoumarin (4-methylumbelliferone, coumarin 4 or 4-MU) and 7-diethylamino-4-methylcoumarin (coumarin 1 or MDAC), both from Sigma-Aldrich, and ethanol (Prolabo, Barcelona, Spain) were used in the extractant drop. 5×10^{-3} mol L^{-1} coumarin stock solutions were prepared in ethanol. Further dilutions of these solutions were prepared in 40% (v/v) ethanol.

Different polar (protic and aprotic) and non-polar solvents were used in preliminary experiments: ethanol, methanol (Prolabo), butanol (Prolabo), 2-propanol (Merck, Darmstadt, Germany), octanol (Sigma-Aldrich), ethylacetate (Probus, Barcelona, Spain), dichloromethane (Panreac), trichloromethane (Sigma-Aldrich), n-hexane (Scharlau, Sentmenat, Barcelona), benzene (Panreac) and toluene (Prolabo).

Interference studies were carried out using ethanol, methanol, butanol, 2-propanol, pinene [(1S,5S)-2,6,6-Trimetilbiciclo[3.1.1]hept-2-ene] (Sigma-Aldrich), α-isomethyl-ionone [3-methyl-4-(2,6,6-trimethyl-2-cyclohexen-1-yl)-3-buten-2-one] (Sigma-Aldrich) and citronellol [3,7-Dimetiloct-6-en-1-ol] (Sigma-Aldrich).

Different commercial cosmetics were analyzed: deodorant cream, baby cream, cream for atopic skin and anti-wrinkle cream.

2.3. HS-SDME procedure

0.5 g of cosmetic sample were accurately weighed in a 1 mL vial containing a stirring bar. The vial was closed and a 2.5 μL-aqueous drop containing 3×10^{-4} mol L^{-1} 4-MU or 6×10^{-6} mol L^{-1} MDAC in 40% (v/v) ethanol at 4 °C was exposed for 3 min to the headspace above the stirred sample at 1500 rpm. Then, the drop was withdrawn into the microsyringe and 2 μL of it were placed on the fluorospectrometer pedestal for the measurement (I, fluorescence intensity). Fluorescence of coumarin solution (I_0) was used in order to calculate I_0/I for 4-MU ('turn off') or I/I_0 for MDAC ('turn on').

3. Results and discussion

3.1. Solvent selection

The selection of an adequate solvent for 4-MU and MDAC was of paramount importance, since the fluorophore environment influences emission. Fluorophores and molecules surrounding them form a quantum system affected by different factors such as solvent properties (polarity, ability to form hydrogen bonds and viscosity). In particular, 4- and 7-substituted coumarins are strongly influenced by solvent polarity [16]. 1 mg of 4-MU or MDAC was dissolved in 3 mL of different solvents, including polar protic, polar aprotic and non-polar solvents or observing the fluorescence of the two coumarins and its modulation by acetone (*i.e.*, 'turn-on' or 'turn-off' probes). After measuring the fluorescence intensity (I_0) of both solutions, acetone was directly added and fluorescence intensity (I) was again measured. Fluorescence intensities are shown in Fig. 1. Table 1 shows maximum emission wavelengths and I_0/I and I/I_0 ratios for 4-MU and MDAC, respectively.

As can be seen, I_0 from 4-MU is higher in non-polar solvents such as trichloromethane and hexane (Fig. 1A). According to the Franck–Condon principle, systems undergo relaxation by reorientation of solvation molecules, that is, solvents are reoriented in order to compensate the dipole moment of the fluorophore, hence minimizing the total energy of the quantum system [17]. Accordingly, as can be seen in Table 1, this also produces an additional red shift of wavelengths. When alcohols (*i.e.*, polar protic solvents) are considered, fluorescence intensities are similar in all cases, with

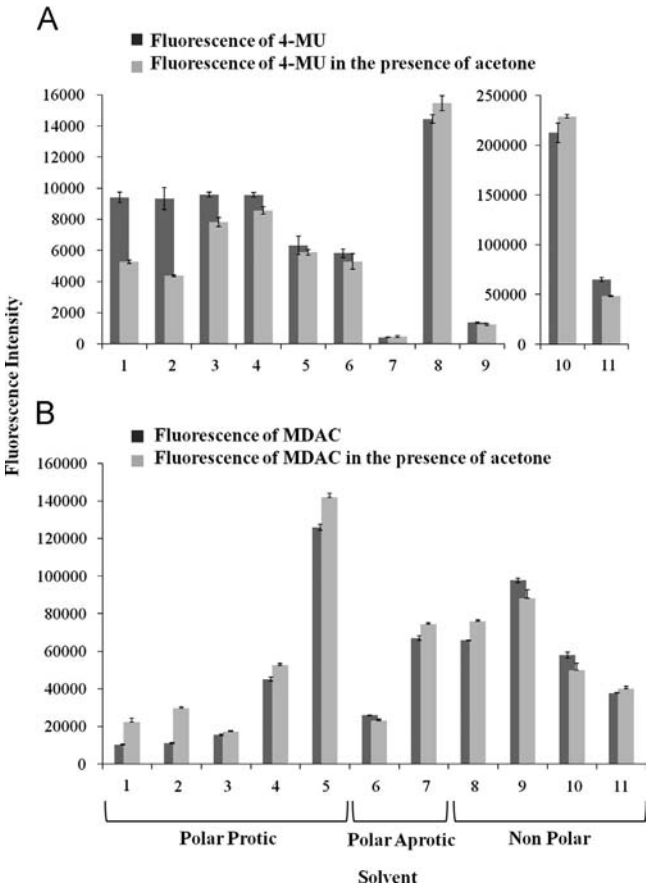

Fig. 1. Fluorescence of coumarins in different solvents and its modulation by acetone: (A) 4-MU and (B) MDAC. (1) methanol; (2) ethanol; (3) propanol; (4) butanol; (5) octanol; (6) ethylacetate; (7) dichloromethane; (8) trichloromethane; (9) toluene; (10) hexane; (11) benzene.

Table 1
Study of the fluorescent behavior of the two coumarins in different solvents and their modulation by acetone.

Solvent	4-MU			MDAC		
	λ em (without acetone)	λ em (with acetone)	I_0/I	λ em (without acetone)	λ em (with acetone)	I/I_0
Methanol	444	444	1.77	459	459	2.15
Ethanol	443	443	2.13	460	460	2.65
Propanol	432	432	1.22	453	453	1.10
Butanol	439	439	1.10	461	461	1.16
Octanol	423	423	1.07	440	440	1.30
Ethylacetate	431	431	1.09	432	431	1.12
Dichloromethane	425	425	1.10	429	429	1.11
Trichrolomethane	416	428	1.07	423	430	1.15
Toluene	416	416	1.10	407	415	0.9
Hexane	424	428	1.07	407	407	1.16
Benzene	411	421	1.34	411	424	1.06

the exception of octanol. Alcohols with less than six carbon atoms have the same orientational distribution of terminal methyl group irrespective of chain length, thus forming a fairly well-ordered hydrogen bonding network. For six or more carbon atoms, *e.g.*, octanol, some defects can occur in the distribution that can cause the coumarin rotation and, as a consequence, fluorescence decreases [18].

When results for MDAC are considered (Fig. 1B), an increase in I_0 is observed on increasing length of alcohol used (maximal signal with octanol). The orientational dynamics of this coumarin in different solvents have been considered by Gustavsson et al. [19] as complex. These authors predicted much slower reorientational times in the case of protic alcohols by introducing an additional dielectric friction. Non-equilibrium interactions between solute and solvent with continuous solvent reorganization and hydrogen-bonds making and breaking, have been considered. Barik et al. [20] also found unusual photophysical properties in nonpolar solvents for this coumarin. These authors proposed a non-polar structure (7-NEt2 group has a pyramidal configuration) in non-polar solvents and a polar structure (intramolecular charge transfer) in polar solvents. As in the previous case, a red shift of wavelengths is observed (Table 1).

When acetone is added to coumarin solutions, the larger changes in fluorescence are obtained in the shorter-chain alcoholic solvents, *i.e.*, methanol and ethanol for both coumarins (Fig. 1 and Table 1). In general, fluorescence 'turn off' and 'turn on' were observed for 4-MU and MDAC solutions, respectively. In all cases, maximum wavelengths of emission were the same with and without acetone, with some exceptions for non-polar solvents (maximum shift: 13 nm). The aprotic acetone can contribute to modify the well-ordered hydrogen bonding network formed by short chain alcohols, in special methanol and ethanol. As a consequence, 4-MU rotation is facilitated and then, fluorescence decreases. A Stern–Volmer behavior was observed for this coumarin in ethanol (I_0/I=89.8 [μg acetone]+0.99, r^2 0.9933). In the case of MDAC, the additional dielectric friction is likely reduced by acetone molecules and I is increased. A Stern–Volmer behavior was also found (I/I_0=166.4 [μg acetone]+1.0, r^2 0.9957).

In view of the above results, ethanol (I_0/I, 2.13 for 4-MU and 2.65 for MDAC) and methanol (I/I_0, 1.77 for 4-MU and 2.15 for MDAC) were selected as possible drop media. Bearing in mind the volatility of these two alcohols (ethanol > methanol), a strong evaporation of drop in HS-SDME procedures can be predicted. A 2.5 μL ethanol drop is stable for 50 s, a drastic reduction of the drop volume being observed at longer times. In the case of methanol, the drop can be suspended in the microsyringe until 4 min. In order to increase the microextraction time, hydroalcoholic mixtures were employed. No significant differences in fluorescence ratio were found for mixtures containing ethanol or methanol in a 40–80% (v/v) range. Under these conditions, the drop can be suspended without volume reduction for a time between 8 and 15 min. So, considering the obtained fluorescence intensity ratios and the toxic nature of methanol, diluted ethanol was selected as drop medium for further studies.

3.2. Headspace volume

Given the high volatility of acetone (vapor pressure at 20 °C: 185 mm Hg), direct extraction of this analyte by stirring untreated cosmetic samples should be feasible as occurs for other organic volatiles [7]. Thus, in this work, acetone is partitioned between cosmetic sample, headspace and extractant drop (ethanol/water solution containing coumarin). For analytes with relatively large air–water distribution constant such as acetone, the amount of analyte extracted in the drop is directly determined by the volume of the headspace [21]. In general, the smaller the headspace volume, the higher the analyte concentration in it, thereby increasing the sensitivity [22].

In this case, a strong dependence of headspace or vial volume was observed. Then, different vials with a volume in the range of 0.5–40 mL were tested. As can be seen in Fig. 2, both coumarins show a similar behavior. Maximum ratios of fluorescence intensity were found between 0.5 and 1 mL. Then, in order to ensure a compromise between sample mass (maximum sensitivity) and minimum headspace volume, 1 mL vials were selected.

3.3. Composition, volume and drop temperature

Selection of the most suitable extractant phase is essential in HS-SDME procedures. As a consequence, the concentrations of coumarin and ethanol were studied. 4-MU concentration was studied between 3×10^{-6} and 3×10^{-3} mol L^{-1}, and MDAC concentration between 2×10^{-4} and 2×10^{-8} mol L^{-1}. In both cases, 30% (v/v) ethanol was used as medium, along with a 2.5 μL drop volume and 5 min of microextraction time. Results are shown in Fig. 3. In the case of 4-MU, maximum I_0/I was obtained for concentrations higher than 3×10^{-5} mol L^{-1}, and consequently, a 3×10^{-4} mol L^{-1} concentration was selected for further studies. For MDAC, maximum ratio was obtained at a concentration between 2×10^{-6} and 2×10^{-7} mol L^{-1} and therefore, 6×10^{-6} mol L^{-1} was selected.

Under these conditions, the effect of ethanol concentration in the drop was tested in the range 20–50% (v/v) for both coumarins since higher concentrations led to the fall of the drop. In the view

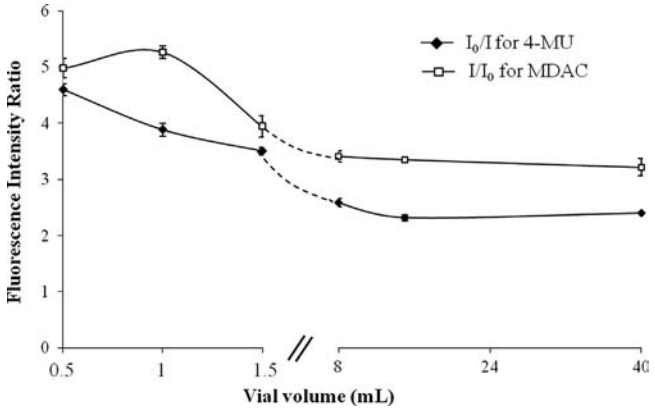

Fig. 2. Study of the effect of the headspace volume on the fluorescence intensity ratios of 4-MU and MDAC.

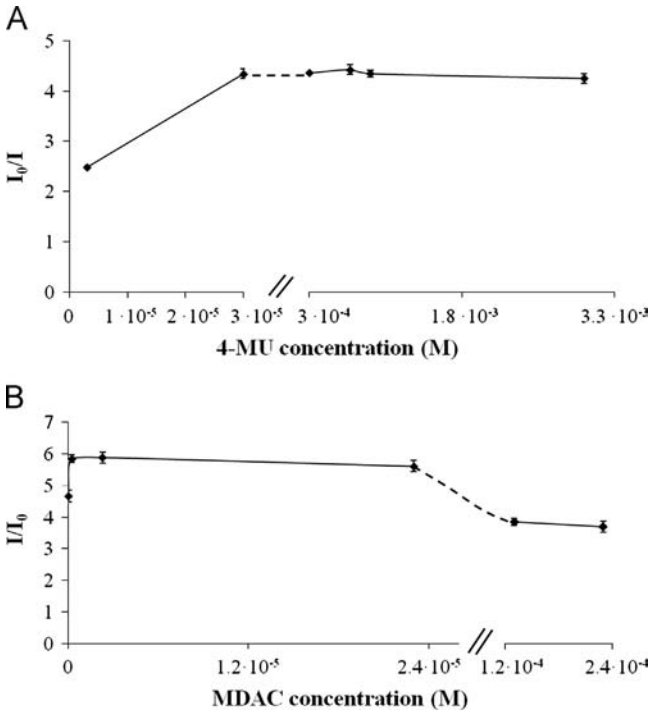

Fig. 3. Optimization of the concentration of 4-MU and MDAC in the extractant drop.

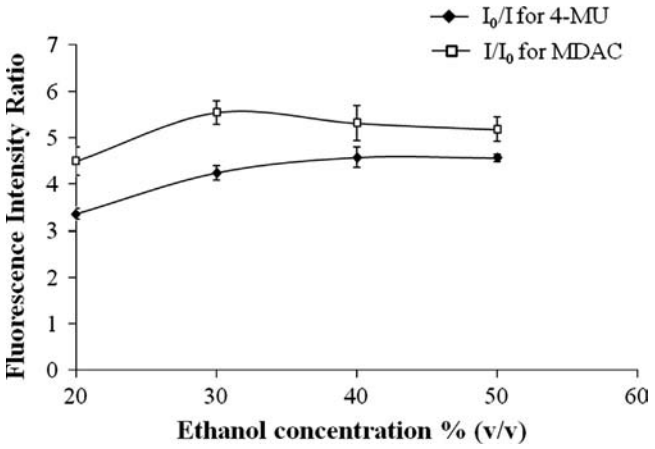

Fig. 4. Optimization of the ethanol concentration in the extractant drop.

of the results (Fig. 4), a concentration 40% (v/v) ethanol was selected.

In general, an increase in the superficial area of the drop gives rise to an increase in the extraction efficiency. However, high drop volumes can compromise the stability and further fall of the drop [22]. Then, drop volume was studied between 1.5 and 3 μL for both 4-MU and MDAC. Results showed an increase in fluorescence ratios with higher drop volumes, however, drop volumes of 3 μL caused a frequent fall of the drop when acetone is extracted. Then, a 2.5 μL-volume was selected.

The fluorescence yield of coumarins is affected by temperature [23]. In this case, a remarkable influence of this parameter was observed. Both I_0 and I increase with increasing temperature, but in different proportions. As a result, a decrease in fluorescence ratio was observed. For this reason, drop temperature was tested between −4 and +23 °C. To this end, extractant solutions were previously thermostatized. The results are shown in Fig. 5. In general, a progressive decrease in the I_0/I ratio and a worsening of

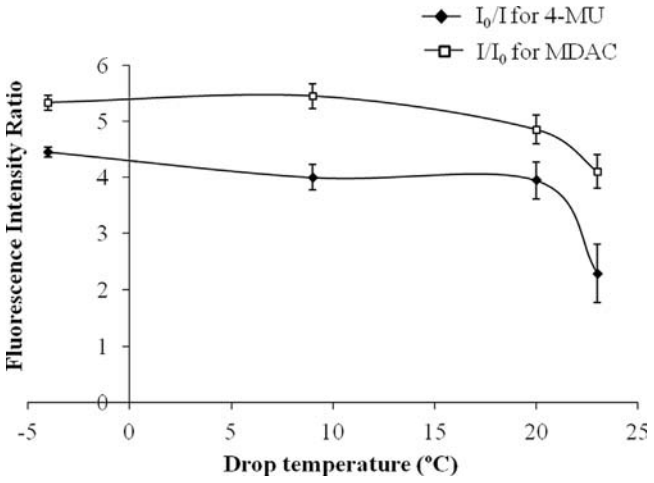

Fig. 5. Influence of temperature of the extractant drop.

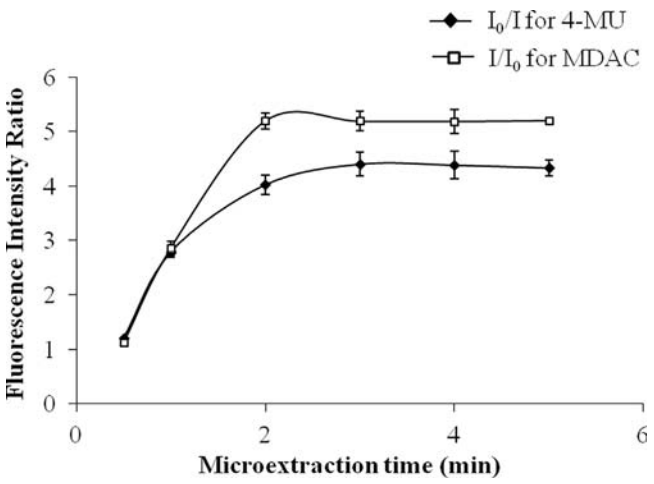

Fig. 6. Study of the microextraction time.

precision were observed with increasing temperature. Then, −4 °C was selected as optimal drop temperature (extractant solution is stored in the freezer at this temperature).

3.4. Microextraction time

Given the volatile nature of the analyte, an initial downtime can favor the headspace saturation, thus improving the subsequent mass transfer to the extractant drop [22]. As a consequence, the effect of a downtime prior to microextraction was studied in a range of 0–15 min. Results did not show a significant effect on the extraction efficiency, and therefore, no initial downtime was used in this work.

Mass transfer processes are directly related to the time of drop exposition, which makes microextraction time a very important parameter in HS-SDME [22]. This parameter was studied between 0.5 and 5 min. As can be seen in Fig. 6, equilibrium is rapidly reached for both coumarins (maximum fluorescence ratios were obtained at 2–3 min). Since chemical derivatization is unnecessary, a rapid mass transfer and diffusion of acetone in the ethanol–water drop can be predicted.

3.5. Stirring rate, mass and temperature of sample

Volatile analytes are more efficiently transferred to the headspace when the sample is under constant stirring [22]. Then, this

Table 2
Effect of sample mass on recovery.

Sample mass (g)	Recovery (%)	
	4-MU	MDAC
0.1	106 ± 1	102 ± 2
0.2	106 ± 2	100 ± 3
0.3	99 ± 4	99 ± 4
0.4	98 ± 4	99 ± 5
0.5	102 ± 6	99 ± 5
0.75	94 ± 8	96 ± 10
1	88 ± 8	83 ± 8
1.2	84 ± 10	72 ± 10

parameter was studied between 0 and 1500 rpm (maximum rate) with the cream deodorant (*i.e.*, a very viscous sample) spiked with acetone. Inefficient extractions were observed at lower stirring rates than 1300 rpm. Maximum rate was selected.

Working with a sample mass as large as possible should be desirable for achieving the highest sensitivity, however, stirring can be ineffective with large amounts of sample. Then, recovery studies with different masses of deodorant sample (0.1–1.2 g) were carried out. As can be seen in Table 2, results were found to be quantitative up to 0.5 g sample. Higher sample masses gave rise to a loss in magnetic stirring efficiency, thus decreasing the precision and/or recovery.

In general, an increase in the sample temperature leads to a higher concentration of acetone in the headspace. However, an excessive temperature can cause drop evaporation and a decrease in the fluorescence ratio, as shown in Fig. 5. Sample temperature was studied between 0 and 50 °C by thermostatizing the microextraction vial. Temperatures higher than 18 °C gave rise to a significant decrease in the fluorescence ratio, a 10 °C temperature being finally selected.

3.6. Possible interferents

While it is true that different species (*e.g.*, halides, metals, *etc.*) can cause coumarin fluorescence quenching [12], the use of headspace microextraction limits potential interferences to volatile substances present in cosmetics, especially alcohols and fragrances. Then, the effect of different common alcohols and fragrances in cosmetics was studied with the sample of deodorant (*i.e.*, a cosmetic without alcohol and fragrance free). For this purpose, microextraction was carried out spiking only acetone and acetone together with ethanol, methanol, propanol, butanol, citronellol, α-isomethyl ionone or pinene. As can be seen in Table 3, only citronellol caused a certain interferent effect when MDAC is used in the drop (recovery 120%).

3.7. Validation of the proposed method

Analytical characteristics were obtained for the proposed methodology. Typical equations of external calibration were found to be $I_0/I = 630.24$ [μg acetone] + 1.04 (r^2 0.9953) for 4-MU, and $I/I_0 = 1075.8$ [μg acetone] + 2.65 (r^2 0.9962) for MDAC. Calibration curves were found to be linear up to 160 μg acetone.

Limits of detection (LODs), calculated according to the 3σ criterion and considering a sample mass of 0.5 g were found to be 0.26 μg g^{-1} for MDAC and 0.55 μg g^{-1} for 4-MU. Accordingly, limits of quantification (LOQs), calculated using the 10σ criterion were found to be 0.87 μg g^{-1} for MDAC and 1.84 μg g^{-1} for 4-MU.

Precision, evaluated as repeatability, was expressed as RSD (%). Deodorant sample spiked with 50 μg of acetone was analyzed

Table 3
Effect of potential interferents on the fluorescence intensity ratio of 4-MU and MDAC.

Interferent	4-MU		MDAC	
	I_0/I	Recovery (%)	I/I_0	Recovery (%)
Acetone	4.55	–	5.20	–
Methanol	4.58	101	5.17	99
Ethanol	4.49	99	5.18	100
Propanol	4.51	99	5.06	97
Butanol	4.45	98	4.90	96
Citronellol	4.21	94	6.15	120
Isomethyl-ionone	4.47	98	5.32	103
Pinene	4.61	101	5.35	103

Table 4
Analytical results and recovery study for different cosmetic samples.

Sample	Found acetone	Recovery (%)	
	(μg g^{-1})	4-MU	MDAC
Deodorant	< LOD	105 ± 5	103 ± 4
Baby cream	< LOD	92 ± 3	90 ± 3
Cream for atopic	< LOD	107 ± 2	109 ± 2
Anti-wrinkle cream	< LOD	94 ± 3	89 ± 2

(*n* 5). Under these conditions, RSDs were 5.3% for 4-MU and 4.7% for MDAC.

Cosmetic samples were analyzed following the proposed HS-SDME procedure and using external calibration. As can be seen in Table 4, the residual acetone concentration was below the LODs in all cases. Then, accuracy was evaluated by means of recovery studies. Results obtained for three replicates are shown in Table 4. As can be noted, quantitative recoveries were obtained for all analyzed samples.

Analytical characteristics of several methods for acetone determination in different matrices are shown in Table 5. In this work, good LODs, high sample throughput and comparable precision are obtained with regard to other methodologies. Whereas around 4 min are required with the proposed HS-SDME procedure (3 min for microextraction and 1 min for measurement), a minimum analysis time of 24 min is required for gas chromatographic analysis. The use of a simpler and much lower cost-affordable instrumentation in comparison with gas chromatographic techniques can be emphasized.

4. Conclusions

In this work, a new HS-SDME procedure based on modulation of coumarin fluorescence by acetone ('turn off' for 4-MU and 'turn on' for MDAC) provides a fast and simple assay for residual acetone determination in cosmetic samples. The choice of a suitable coumarin solvent for the drop was of paramount importance since the environment of fluorophore influences the emission spectrum, in special polarity, and hydrogen bonding ability of solvent. An ethanol–water (40% v/v) drop leads to maxima fluorescence changes when acetone is extracted. Moreover, it is noteworthy that no sample pretreatment was necessary. This provides an important advantage because cosmetics are very complex samples and usually laborious and time consuming sample pretreatment procedures are required. For example, Zhao et al. [3] determined acetone in cosmetics using a purge and trap system followed by Gas Chromatography–Photo Ionization detector, which

Table 5
Comparison of the proposed method with other analytical methodologies for the determination of acetone in different samples.

Method	Matrix	Estimated anal. time ($_{min}$ per sample)	LOD	Linear range	RSD (%)	Ref.
Purgue and trap-GC-FID	Cosmetics	35	2.7[a]	n.i.	5.1	[3]
HS sampling-GC-FID	Drug intermediates	24	7[b]	0.008-0.4[c]	4.9	[24]
HS sampling-GC-FID	Pharmaceuticals	40	2[d]	20-6000[d]	2	[25]
SPME-GC-FID	Pharmaceuticals	60	1.7[d]	2-11.8[d]	3.8	[26]
HS-SDME-microvolume fluorospectrometry	Cosmetics	4	0.26-0.55[e]	Up to 160[f]	5	This work

[a] Values expressed as $\mu g\ L^{-1}$.
[b] Values expressed as ppm.
[c] Values expressed as $\mu L\ mL^{-1}$.
[d] Values expressed as $\mu g\ mL^{-1}$.
[e] Values expressed as $\mu g\ g^{-1}$.
[f] Values expressed as μg; n.i. is not indicated.

undoubtedly is difficult to implement in routine laboratories. A high sample throughput can also be highlighted, since 3 min are only required for microextraction, and fluorescence measurements are carried out in less than 10 s.

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References

[1] Making Cosmetics: Solvents and Stabilizers, ⟨http://www.makingcosmetics.com/Solvents-Stabilizers-c37/⟩ (accessed February 2014).
[2] G. Wypych, in: G. Wypych (Ed.), Handbook of Solvents, ChemTec Publishing, Toronto, 2001, pp. 881–882.
[3] Y. Zhao, S. Lua, C. Liu, Z. Meng, C. Ni, Q. Cao, M. Miao, Int. J. Chem. 2 (2010) 55–64.
[4] SIDS Initial Assessment Report (SIAR) for the 9th SIAM: Acetone CAS No: 67-64-1, UNEP Publications, 1999, pp. 1–118.
[5] Y. Zhao, S. Lu, C. Liu, Z. Liu, Z. Meng, C. Ni, Q. Cao, M. Miao, Guangpu Shiyanshi 26 (2009) 1316–1319.
[6] E. Huzar, A. Wodnicka, M. Dzieciol, Proc. ECOpole 4 (2010) 263–266.
[7] N. Cabaleiro, I. de la Calle, C. Bendicho, I. Lavilla, Anal. Chim. Acta 733 (2012) 28–33.
[8] N. Cabaleiro, I. de la Calle, C. Bendicho, I. Lavilla, Anal. Chim. Acta 719 (2012) 61–67.
[9] M.D.M. Abadi, N. Ashraf, M. Chamsaz, F. Shemirani, Talanta 99 (2012) 1–12.
[10] K.N. Venugopala, V. Rashmi, B. Odhav, BioMed. Res. Int. 2013 (2013) 1–14.
[11] M.M. Husain, R. Sindhu, H.C. Tandon, Eur. J. Chem. 3 (2012) 87–93.
[12] B.D. Wagner, Molecules 14 (2009) 210–237.
[13] E.R. Ale, A. Olives, L. Martín, M. Martín, B. del Castillo, A. Agnese, M. Ortega, S. Núñez-Montoya, J.L. Cabrera, ARS Pharm. 43 (2002) 57–71.
[14] V.K. Sharma, D. Mohan, P.D. Sahare, Spectrochim. Acta Pt-A 66 (2007) 111–113.
[15] A. Pattanaik, M. Nanda, P.D. Sahare, Proc. SPIE 6405 (2006) 640514, http://dx.doi.org/10.1117/12.698100.
[16] H. Li, L. Cai, Z. Chen, H. Li, L. Cai, Z. Chen, in: W. Wang (Ed.), Advances in Chemical Sensors, In Tech Publisher, Viena, 2012, pp. 121–150.
[17] J.R. Lakowicz, Principles of Fluorescence Spectroscopy, third ed., Springer Science, New York, 2006.
[18] C.D. Stanners, Q. Du, R.P. Chin, P. Cremer, G.A. Somorjai, Y.R. Shen, Chem. Phys. Lett. 232 (1995) 407–413.
[19] T. Gustavsson, L. Cassara, S. Marguet, G. Gurzadyan, P. van der Meulen, S. Pommeret, J.C. Mialocq, Photochem. Photobiol. Sci. 2 (2003) 329–341.
[20] A. Barik, M. Kumbhakar, S. Nath, H. Pal, Chem. Phys. 315 (2005) 277–285.
[21] K.M. Kokosa, A. Przyjazny, M. Jeannot, Solvent Microextraction, first ed., John Wiley and Sons Inc, New Jersey, 2009.
[22] F. Pena-Pereira, I. Lavilla, C. Bendicho, Anal. Chim. Acta 669 (2010) 1–16.
[23] T.V. Sakhno, I.V. Korotkova, O.A. Khakhel, Theor. Exp. Chem. 32 (1996) 217–220.
[24] E. Quirk, A. Doggett, A. Bretnall, J. Pharm. Biomed. Anal. 96 (2014) 37–44.
[25] J. Somuramasami, Y.C. Wei, E.F. Soliman, A.M. Rustum, J. Pharm. Biomed. Anal. 54 (2011) 242–247.
[26] S.O. Akapo, C.M. McCrea, J. Pharm. Biomed. Anal. 47 (2008) 526–534.