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Application of quantum dots in clinical and alimentary fields using multicommutated flow injection analysis

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ABSTRACT

In recent years, the number of scientific papers regarding the use of quantum dots (QDs) has increased almost exponentially, especially emphasizing their use for new applications and describing new approaches. One of the future trends in the development of new methods of analysis is the use of automated methodologies. Among them, Multicommutated Flow Injection Analysis has been here selected in order to show its potentiality in pharmaceutical and food analysis.

Using water-soluble CdTe QDs modified by mercaptopropionic acid, a flow system was developed for the determination of ascorbic acid. The system was based on the quenching effect produced by ascorbic acid on the fluorescence of QDs. Under the optimized conditions, the relationship between the fluorescence intensity of the QDs and ascorbic acid concentration was linear in the range of 12–250 μg mL^{-1}, obtaining a sample throughput of 68 determinations per hour. The proposed method was applied to the determination of ascorbic acid in pharmaceutical formulations, goji capsules and fruit juices. The results obtained were in good agreement with those showed by a reference method, so indicating the utility of the proposed method in the clinical and alimentary fields.

1. Introduction

Quantum dots (QDs) are colloidal semiconductor nanocrystals formed from group II–IV, III–V or IV–VI materials, such as those made of CdSe and CdTe. They have a narrow distribution density of energy states, strongly dependent on the dimensions of the confining potential with electronic confinement occurring in all spatial dimensions (3-D). These nanoparticles display superior luminescent properties, including high quantum yield of fluorescence, broad excitation spectrum, narrow/symmetric emission spectrum, size- and composition-tunable emission wavelength, high photobleaching threshold and excellent photostability. Therefore, thanks to recent advances in nanotechnology and nanomaterials, QDs are replacing conventional organic fluorophores for the design of fluorescence chemical and biological probes with different applications, such as the determination of biomolecules [1–4]. The scientific references found in the literature concerning QDs have increased throughout the years, with more than 4000 papers published each year over the last decade [5]. This productivity points out the wide acceptance by the scientific community of QDs for the development of new innovations and applications. In recent years several articles have been published regarding the use of QDs for the determination of contaminants in food samples [6–12]. Different analytical approaches have been used, such as immunosorbent assays [12] or the use of capillary chromatography [6] or capillary electrophoresis [7,11] as separation techniques. Other active field of research is the analysis of pharmaceutical formulations [13–16]. However, despite the great number of analytical applications making use of QDs nanotechnology, only a very restricted number of works are based on automated approaches [14,17–19], especially in food analysis.

The use of automated flow methodologies allows the development of environmental-friendly methods and to prevent operators to come into contact with toxic materials. The main goal of the present work is to combine Multicommutated Flow Injection Analysis (MCFIA) and QDs, showing its potentiality for the analysis of pharmaceutical and food samples. This coupling has not been described yet in scientific literature. In MCFIA, the employment of discrete commutation devices (solenoid valves) allows an easy reconfiguration of the manifold by means of the software procedure. Each analytical step can be independently implemented increasing the versatility of the flow system. This methodology combines the advantages of Flow Injection Analysis (FIA) such as high injection throughput, with those given by Sequential Injection Analysis (SIA), i.e. minimal reagent consumption and wastes generation [20,21], being this last characteristic necessary and very important that takes into account the presence of heavy metals in QDs structure.

Ascorbic acid (AA, vitamin C), an important water-soluble antioxidant in chemical and biological systems, has been selected as a model analyte. This nutrient, which can be supplied only by

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the diet, is a natural compound that appears in fruits and vegetables, and it is also used as an essential additive in the food processing industry. Therefore simple, sensitive and selective methods, which can provide precise and accurate results, are required for its determination. To date, numerous methods have been developed for the analysis of AA in food (fruits and vegetables), pharmaceuticals and biological fluids including enzymatic [22,23], electrochemical [24,25], spectrophotometric [26,27], fluorimetric [28,29] and chromatographic [30,31] techniques. However, complicated extraction procedures, high cost, long operation time and lack of selectivity were sometimes found in their application.

Mercaptopropionic acid (MPA) capped CdTe QDs with different particle sizes were successfully synthesized in aqueous medium and applied to the quantitative determination of AA in different pharmaceuticals and food samples (goji capsules and cranberry, apple and orange juices). The developed approach was based on the monitoring of QDs' fluorescence quenching produced by AA, using MCFIA as the flow system. A reference method was also used in order to check the results obtained by the proposed method, observing no significant statistical differences between both methods.

2. Materials and methods

2.1. Reagents and solutions

CdTe QDs were synthetized using tellurium powder (200 mesh, 99.8%), sodium borohydride ($NaBH_4$, 99%), cadmium chloride hemi (pentahydrate) ($CdCl_2 \cdot 2.5H_2O$, 99%) purchased from Sigma-Aldrich (St. Louis, MO, USA); and 3-mercaptopropionic acid (MPA, 99%) and absolute ethanol (99.5%) obtained from Fluka (St. Louis MO, USA) and Panreac (Barcelona, Spain), respectively. For adjusting the alkalinity of the reaction medium, a 1.0 mol L^{-1} NaOH solution was used. QDs solutions were prepared by dissolving a certain amount of the dried nanocrystals in ultrapure water and used directly.

AA ($\geq$ 99%), sodium hydroxyde (NaOH, 98%), disodium hydrogen phosphate 2-hydrate ($Na_2HPO_4 \cdot 2H_2O$, 99%) and the excipients used in the interference study were obtained from Sigma (Madrid, Spain). AA standard solutions of 500 mg L^{-1} were prepared daily and were protected from light using aluminum foil.

2.2. Instrumentation

For the characterization of the synthesized QDs, absorbance and fluorescence spectra were recorded using a Jasco V-660 spectrophotometer and a PerkinElmer LS-50B luminescence spectrometer, respectively. QDs centrifugation was performed with a ThermoElectron Jouan BR4I refrigerated centrifuge.

The flow system (Fig. 1) was built with: one four-channel Gilson Minipuls-3 peristaltic pump (Villiers le Bel, France), fitted with a rate selector and pump tubing type Solvflex (Elkay Products, Shrewsbury, MA, USA); three 161T031 NResearch three-way solenoid valves (Neptune Research, MA, USA); and an electronic interface, based on ULN 2803 integrate circuits, to generate the electric potential (12 V) and current (100 mA) required to control the valves. PTFE tubing (0.8 mm i.d.) and methacrylate connections were also used. The software for controlling the system was developed by our research group using Visual Basic 6.0.

Luminescence measurements in the flow system were performed with a Cary-Eclipse Luminescence Spectrometer (Varian Inc., Mulgrave, Australia) controlled by a computer equipped with a Cary-Eclipse (Varian) software package for data collection and treatment. Instrument excitation and emission slit widths were set at 5 and 10 nm, respectively. The detector voltage was 670 V and the excitacion and emission wavelengths were 285 and 628 nm, respectively. A Hellma flow cell 176.752-QS (25 µl of inner volume and a light path length of 1.5 mm) was used too. All experiments were carried out at room temperature.

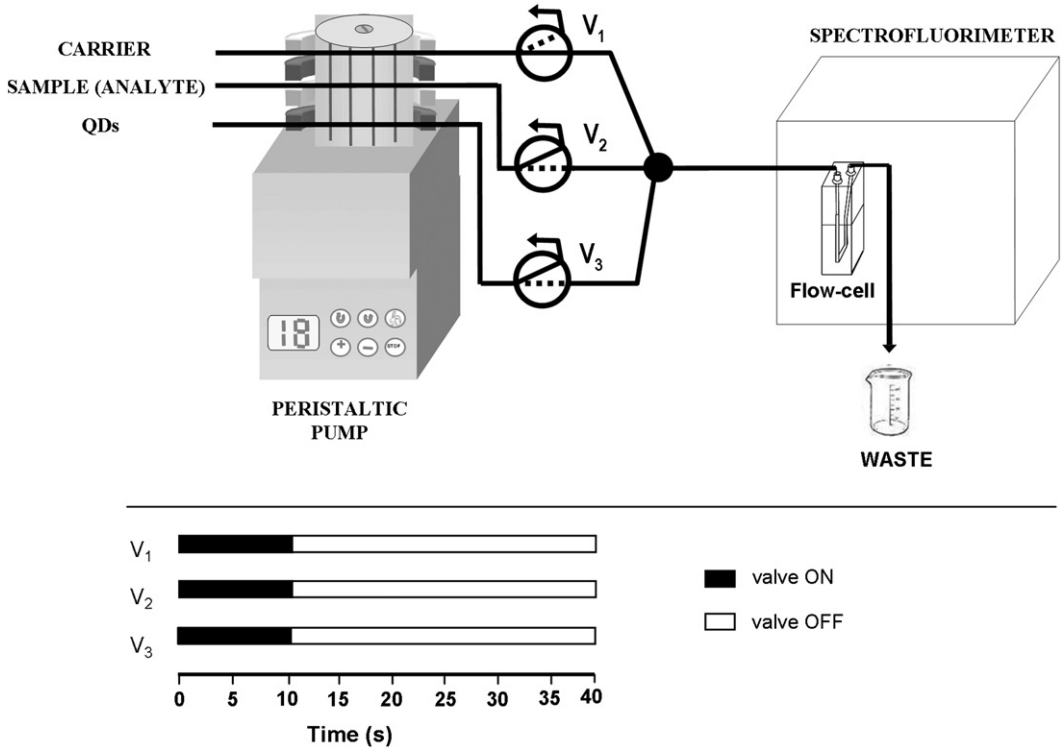

Fig. 1. MCFIA manifold. Scheme of the solenoid valves (V_1, V_2 and V_3) procedure is shown.

2.3. Synthesis of QDs

The synthesis of the QDs used in this work was carried out as described by Zou et al. [32] with some modifications. Briefly, the reaction between $NaHB_4$ (1.6×10^{-3} mol) and the tellurium powder (0.4×10^{-3} mol) was carried out in N_2 saturated water, inside a 50 mL flask at 80 °C for 30 min, under constant stirring. The resulting NaHTe solution was transferred to another flask containing 4.0×10^{-3} mol $CdCl_2$ and 6.8×10^{-3} mol MPA in a 100 mL N_2 saturated water solution. The pH of the solution was adjusted to 11.5 by addition of 1.0 mol L^{-1} NaOH solution. The Cd^{2+}:Te^{2-}:MPA molar ratio was fixed as 1:0.1:1.7. The CdTe QD size was tuned by varying the heating time. In order to remove the contaminants, purification of QDs was performed by precipitation in absolute ethanol. The precipitate fractions were subsequently centrifuged, vacuum dried and kept in the refrigerator. All the fractions obtained were re-suspended in deionised water maintaining the initial synthesis concentration and the diameter of CdTe QD was calculated by the following expression [33]:

$$D=(9.8127\times10^{-7})\lambda^3-(1.7147\times10^{-3})\lambda^2+(1.0064)\lambda-194.84$$

where D is the diameter of the nanocrystals (nm) and λ is the wavelength of maximum absorbance corresponding to the first excitonic absorption peak of the crystal.

To facilitate the preparation of the QDs solutions was also necessary to calculate the molar weight of the different sized nanocrystals. This was carried out by establishing firstly the extinction coefficient (ε) by using the expression [33] $\varepsilon=3450\Delta E(D)^{2.4}$, where ΔE is the transition energy corresponding to the first absorption peak and the unit is in eV. Knowing ε it was simple to reach the molar mass by measuring the absorbance of a known concentration solution and by applying the Lambert–Beer law.

2.4. Sample preparation

Goji capsules and fruit juices were obtained from local markets, and all pharmaceutical formulations (Spanish pharmacopoeia) were obtained from a local pharmacy.

For the measurement of AA content in fruit juices, only 10-fold dilutions with 0.02 mol L^{-1} Na_2HPO_4 buffer solution, pH 11.5, were required. For the goji capsules, 10 capsules were emptied and the content homogeneously mixture. Then, the weight corresponding to one capsule was dissolved in 100 mL deionized water and, after centrifugation 3 min at 4000 rpm, a 10-fold dilution with 0.02 mol L^{-1} Na_2HPO_4 buffer was made before the analysis.

The preparation of the pharmaceuticals was as follows: 10 tablets/packets of each pharmaceutical formulation were accurately weighed and finely ground. A portion of the powder obtained, equivalent to the average weight of a tablet/packet, was transferred to a 100 mL volumetric flask and completed to volume with deionized water. In the case of ampoules, their content was directly dissolved in 100 mL deionized water. In all cases, after sonication, the solutions were filtered if required and appropriate dilutions with 0.02 mol L^{-1} Na_2HPO_4/NaOH buffer solution, pH 11.5, were made before analysis.

2.5. General MCFIA procedure

The schematic valve system diagram is shown in Fig. 1. Each valve can adopt two positions, "ON" and "OFF". When no electric current is applied the valves are in OFF position and the solutions flow through the straight lines, whereas the application of electric current changes the valves to ON position and the solutions flow through the dotted lines. All experiments were carried out in triplicate, and results are expressed as peak height mean values. In order to stabilize the flow system, in the initial status, all valves were switched off and the carrier solution (0.02 mol L^{-1} Na_2HPO_4 buffer solution, pH 11.5) was flowing through the flow-cell (flow rate 2.1 mL min^{-1}) while all other solutions were recycled to their vessels. Then, all valves (V_1, V_2 and V_3) were switched on for 10 s. In this way the direct confluence between QDs (2 μmol L^{-1}, 3.6 nm) and sample solutions (both prepared in 0.02 mol L^{-1} Na_2HPO_4 buffer solution, pH 11.5) took place, whereas the carrier solution was recycled to its vessel. The QDs-sample mixture was directed to the spectrofluorimeter, recording the corresponding analytical signal. A blank has to be recorded before any samples are analyzed, because the analytical signal used is the fluorescence decrease (quenching effect induced by AA). Taking into account the flow-rate (2.1 ml min^{-1}), 10 s corresponded to a volume of 350 μL of solution.

3. Results and discussion

3.1. Spectral characteristics

The remarkable quality of QDs particles is clearly seen from several features in the absorption spectra such us the steepness of the absorption onset, the narrow absorption band and the occurrence of higher energy transitions. Their high quality also results in strong "band-age" emission, which is tunable by varying particle size.

In this work, four different sized of CdTe-MPA QDs (2.3, 2.9, 3.2 and 3.6 nm) were used, showing maximum emission wavelengths at 545, 565, 588 and 628 nm, respectively. The emission wavelength is proportionally increased with QDs size through a red-shift phenomenon. See Fig. 2.

Preliminary studies showed that AA interacted with MPA-capped CdTe QDs reducing their photoluminescence emission by means of a quenching mechanism. A possible mechanism of this quenching relies on the effect of oxygen on the fluorescence of MPA-CdTe-QDs. It was previously reported that, in aqueous solution, oxygen can reversibly enhance the fluorescence of nanocrystals by passivating surface defects [34]. Since AA is a well-known antioxidant, it can easily react with the oxygen adsorbed onto the surface defect of QDs and influence the fluorescence of these nanoparticles. Therefore, the observed quenching of the fluorescence in response to AA presence could

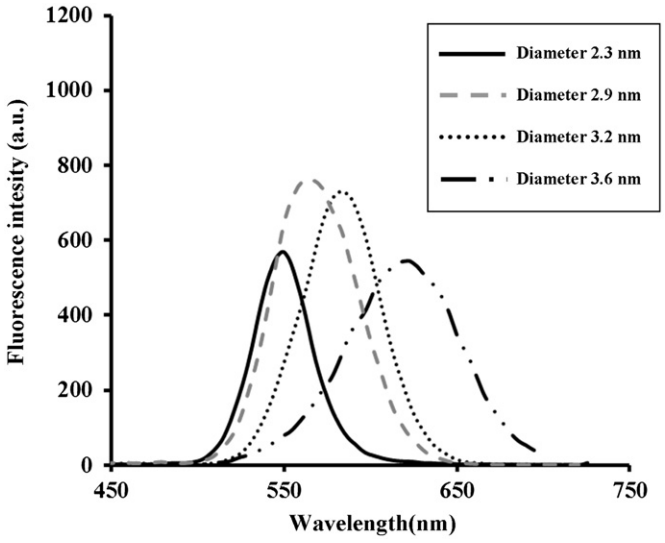

Fig. 2. Emission spectra of QDs for different diameters (2.3, 2.9, 3.2 and 3.6 nm).

be attributed to the displacement of oxygen from the MPA-CdTe-QDs surface. In addition, interactions between electron-donor groups on the AA molecules and incompletely coordinated Cd^{2+} on the QDs surface could result in the establishment of mid-gap energy levels that could act as electron-trapping states preventing electron–hole recombination and yielding a quenching of the nanocrystal photoluminescence.

3.2. Chemical variables

The fluorescence properties of QDs and the interaction between them and the analyte are highly governed by both the QDs size and concentration, and the pH value. Therefore, the effect of these variables on the analytical signal had to be studied. The pH study was carried out for the four diameters of QDs (2.3, 2.9, 3.2 and 3.6 nm) synthesized in this work. These QDs tend to aggregate and precipitate at pH values lower than 7. Hence, the study of this variable was carried out in the pH range between 7 and 12.5 using different QDs concentrations for each diameter (higher concentrations are required for lower sizes due to their lower quantum yield [14]). The highest net signal (highest quenching) was obtained at pH 11.5 in all cases.

Then, the effect of QDs concentration was studied using three different ranges, depending on the QDs sizes: 1–4 μmol L^{-1} (diameter 3.6 nm), 2–8 μmol L^{-1} (diameters 2.9 and 3.2 nm) and 6–14 μmol L^{-1} (diameter 2.3 m). In all cases, it was observed that the net signal increased up to the middle value of the tested range and then decreased for higher concentrations. This effect could be explained by a decrease of fluorescence, mainly due to the inner filter effect as a result of re-absorption of emitted radiation, when the QDs concentration reached too high values. The highest net signal was obtained for 3.6 nm, using a concentration of 2 μmol L^{-1}, therefore selecting these values as optimum. The influence of pH value is shown in Fig. 3, using the optimum QDs' size and concentration.

Finally, the effect of the ionic strength on the analytical signal was studied. This study was carried out using a Na_2HPO_4/NaOH buffer solution at pH 11.5 in the 0.0–0.2 mol L^{-1} range. The results obtained showed that the analytical signal was not influenced by the ionic strength. Therefore, the sample and QDs solutions could be directly adjusted with a NaOH solution. However, for the sake of simplicity and ensuring repeatability, a 0.02 mol L^{-1} Na_2HPO_4/NaOH buffer solution was used for the preparation of all solutions.

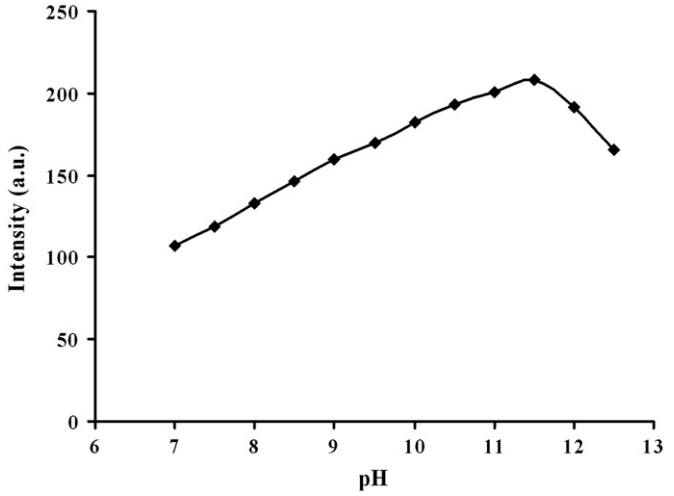

Fig. 3. Effect of the pH on the analytical signal, using a solution containing 2 μmol L^{-1} QDs (3.6 nm) and 150 μg mL^{-1} AA.

3.3. Instrumental variables

Taking into account that the optimum QDs size for the determination of AA was 3.6 nm, the selected wavelengths were 285 nm/628 nm. In order to obtain the best sensitivity, the influence of both the excitation and emission slit widths on the measurements, in the range of 5–20 nm, and the effect of the photomultiplier tube detector voltage, in the range 400–800 V, were studied in the luminescence spectrometer. It was observed that the highest linear dynamic range and sensitivity were obtained when the instrumental conditions were fixed to provide the highest possible signal from the blank solution (only QDs in 0.02 mol L^{-1} Na_2HPO_4/NaOH buffer solution, pH 11.5). As a result, the selected excitation and emission slits were 5 and 10 nm, respectively, whereas the voltage of the photomultiplier tube was set at 670 V.

Other important parameters affecting the magnitude of the analytical signal were the insertion time of sample and QDs solutions, and the effect of the flow rate in the MCFIA system. It has to be stated that the main differences between MCFIA and other flow methodologies is that insertion volumes are replaced with insertion times. Known the flow-rate and the insertion time, the volume can be easily calculated if required.

The same insertion times (5–40 s) for both QDs and sample solutions, making a direct confluence between them just before the flow cell, were tested in the study of the influence of this variable. The analytical signal was highest at 10 s and remained constant for higher values. This effect is explained as follows: the sample is always diluted by the carrier solution; when the time inserted is very low, a high dilution is observed, obtaining a low analytical signal. However, when the sample time is increased, there is a critical point in which the sample dilution is not noticed (10 s in our case), observing the maximum signal. Higher sample times do not improve the analytical signal, only make the peak wider and diminish sample throughput. Therefore, this time was selected as optimum, which corresponds to 350 μL (considering the optimum flow-rate) of each solution.

Regarding the flow-rate, the sample throughput and the repeatability of the system were the analytical parameters considered in order to select the optimum flow-rate. Taking into account that the analytical signal was approximately constant throughout the studied range (1.5–2.5 mL min^{-1}), a flow-rate of 2.1 mL min^{-1} was selected, obtaining a high sample throughput and providing a good repeatability (higher flow-rates diminished the repeatability of the signal).

3.4. Figures of merit

Under the above established optimum conditions, a calibration curve was constructed for AA inserting, by triplicate, sample solutions containing increasing concentrations of the analyte. This was constructed using the net fluorescence signal (blank minus calibration standard signals). Quantification was carried out by using peak height as analytical signal, and data were fitted by standard least-squares treatment. The proposed methodology responded linearly in the AA concentrations range of 12–250 μg mL^{-1}. Detection limit (4 μg L^{-1}) and quantification limit (12 μg L^{-1}) were estimated as the concentrations of analyte that produced analytical signals equal to three and 10 times, respectively, the standard deviation of the background luminescence. The repeatability was established for 10 independent analyses of 50 μg mL^{-1}AA, obtaining a RSD of 2.7%. The sample throughput was calculated as 68 samples per hour, so demonstrating its applicability in routine analysis. All these values are shown in Table 1.

Table 1
Analytical parameters.

Parameter	
Excitation/emission slits (nm/nm)	5/10
Photomultiplier tube voltage (V)	670
Calibration graph	
Intercept	9.6154
Slope (mL μg^{-1})	1.3917
Correlation coefficient	0.9998
Linear dynamic range ($\mu g\ mL^{-1}$)	12–250
Detection limit ($\mu g\ mL^{-1}$)	4
Quantitation limit ($\mu g\ mL^{-1}$)	12
RSD (%) ($n=10$)[a]	2.7
Sampling frequency (h^{-1})	68

[a] 50 $\mu g\ mL^{-1}$ AA.

Table 2
Interference study.

Foreign species	Tolerated interferent/analyte (w/w) ratio[a]
Saccharose, glucose, lactose, fructose, and starch	> 50[b]
Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, and Zn^{2+}	> 5[b]
Niacin, pyridoxine, riboflavin, and thiamine	0.5
Biotin and folic acid	0.1

[a] For a 50 $\mu g\ mL^{-1}$ AA concentration.
[b] Maximum ratio tested.

The ruggedness and robustness of the method were also studied with a 50 $\mu g\ mL^{-1}$ AA solution. The ruggedness of the method was assessed by comparison of the intra- and inter-day assay results undertaken by two analysts; the RSD values did not exceed 3 and 6%, respectively. The robustness of the method was studied under a variety of conditions such as small changes in the pH of sample solution (11.3–11.7), flow-rate (1.9–2.3 mL min^{-1}) and excitation/emission wavelengths (± 2 nm). The percent recoveries for AA were in the 95.0–105.0% range in all cases (considering 100% the value obtained under the optimum conditions). With both studies the ruggedness and robustness of the MCFIA system were demonstrated.

3.5. Interference study

Since the determination of AA was performed in samples from the clinical and alimentary fields, the possible interference from excipients, inorganic elements, and other vitamins commonly found in these samples was investigated. This study was performed by adding different amounts of the possible interfering species to a solution containing 50 $\mu g\ mL^{-1}$ of the target compound. Foreign species were considered not to interfere if they produced an error smaller than $\pm 2\sigma$ in the analytical signal, being σ the standard deviation. The tolerated interferent/analyte ($\mu g\ mL^{-1}$) ratios were much higher than the usual ratios found in the corresponding matrix for all the tested substances (Table 2).

The lower tolerated ratios described for some compounds are not a problem considering the usual concentration in the analyzed samples. For instance, the tolerated ratios for pyridoxine, riboflavin and thiamine were 0.5, whereas the usual ratios found in pharmaceuticals are lower than 0.1. In the case of folic acid and biotin, the usual ratios are lower than 0.006 and the proposed method tolerates a ratio of 0.1. As a result, AA can be analyzed, without significant errors, in the presence of high concentration levels of potentially interfering compounds in pharmaceutical formulations (such as multivitamin preparations), goji capsules and fruit juices.

3.6. Analytical applications

The optimized MCFIA procedure previously described was applied to the determination of AA in goji capsules, fruit juices and pharmaceutical formulations, using the sample treatment described in Section 2.4. The obtained results, shown in Table 3, were in agreement with those ones provided by the manufacturers. The experimental results were compared with those obtained by the AOAC method [35], used as reference method, by means of a *t*-test and an *F*-criterion at a 5% significance level. The AOAC method consists in the titration of AA solutions with 2,6-dichloroindophenol, in the presence of metaphosphoric acid and acetic acid, until a light but distinct rose pink color appears and persists for more than 5 s. In all cases, the average results obtained by both methods were statistically identical, as the difference between the averages had no significance at the probability level indicated.

Table 3
Analytical applications.

Sample	Found[a] (proposed method)	Found[a] (reference method)	t_{calc}[j]	F_{calc}[k]
Goji capsules[b]	28 ± 1	29 ± 1	1.22	1.00
Cranberry juice[c]	408 ± 16	405 ± 18	0.22	0.79
Apple juice[d]	291 ± 12	290 ± 13	0.10	0.85
Orange juice[e]	408 ± 12	399 ± 10	1.00	1.44
Strepsils tablets[f]	101 ± 3	100 ± 3	0.41	1.00
Cebion packets[g]	990 ± 30	993 ± 20	0.14	2.25
AA ampoules[h]	970 ± 20	975 ± 20	0.31	1.00
Berocca tablets[i]	61 ± 2	60 ± 3	0.48	0.44

[a] Means of three determinations, in the same units expressed by the manufacturer.
[b] Amount specified by the manufacturer: 30 mg/capsule.
[c] Amount specified by the manufacturer: 400 mg L^{-1}.
[d] Amount specified by the manufacturer: 300 mg L^{-1}.
[e] Amount specified by the manufacturer: 400 mg L^{-1}.
[f] Amount specified by the manufacturer: 100 mg per tablet (Ltd. Reckitt Benckiser Healthcare).
[g] Amount specified by the manufacturer: 1000 mg/packet (Ltd. Merck Farma Quimica).
[h] Amount specified by the manufacturer: 1000 mg per ampoule (Ltd. Bayer).
[i] Amount specified by the manufacturer: 60 mg per tablet (Ltd. Bayer).
[j] Theoretical value $t=2.776$, $p=0.05$.
[k] Theoretical value $F=19$; $p=0.05$.

Table 4
Recovery study in foods.

Food	Added (mg/100 mL)	Recovery (%)	RSD (%)[a]
Goji capsules	25	103	3
	50	105	4
	75	99	4
Cranberry juice	40	95	4
	80	94	3
	120	103	3
Apple juice	30	105	3
	60	101	3
	100	100	4
Orange juice	40	104	4
	60	92	4
	100	108	4

[a] Means of three determinations.

Table 5
Recovery study in pharmaceutical formulations.

Food	Added (mg)	Recovery (%)	RSD (%)[a]
Strepsils tablets (Ltd. Reckitt Benckiser Healthcare)	50	104	3
	100	98	2
	200	99	3
Cebion packets (Ltd. Merck Farma Quimica)	600	102	4
	1000	104	3
	1400	100	3
AA ampoules (Ltd. Bayer)	500	106	3
	1000	98	2
	1500	95	3
Berocca tablets (Ltd. Bayer)	40	99	4
	60	103	4
	100	100	4

[a] Means of three determinations.

In addition, recovery studies were performed in all the analyzed products, by spiking each sample at three different levels. The obtained results are shown in Tables 4 and 5. It can be observed that the recoveries were in the 92–108% range, with RSDs not higher than 4% in any case.

The method of the average recovery [36] was performed as a significant test in order to assess the accuracy of the method. The average recovery is tested for significance by using the Student *t*-test. The experimental *t* values for the alimentary and pharmaceutical recovery studies were 0.452 and 0.728 ($n=12$). The tabulated *t* value for $n-1$ degrees of freedom and a 95% confidence level is 2.201. Hence, the observed values were lower than the tabulated one, demonstrating the accuracy of the method.

4. Conclusions

A MCFIA system for the determination of AA, based on its quenching effect over the fluorescence of MPA-capped CdTe QDs, has been developed. In order to demonstrate the potentiality of MCFIA for the design of analytical methodologies making use of the outstanding intrinsic characteristics of QDs, several pharmaceutical formulations and food samples (goji capsules and fruit juices) have been selected, and the proposed method applied for the quantitation of AA. It is worth mentioning that this is the first analytical method described for the determination of AA in goji capsules. Analyses with a reference method and recovery studies were also performed in order to demonstrate the accuracy of the MCFIA method. The low consumption of reagents, low wastes generation, high sample-frequency and high automation make MCFIA a strong candidate for future innovations in the QDs research field.

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