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Review

Derivatization strategies for the determination of biogenic amines in wines by chromatographic and electrophoretic techniques☆

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ABSTRACT

This paper revises the derivatization approaches for the determination of biogenic amines in wines. Since most of these amines display poor spectroscopic features to be detected by UV absorption or emission (fluorescence) spectroscopy, derivatization is necessary to attain the desired sensitivity. Reagents such as o-phthaldialdehyde, fluorenylmethylchloroformate, dansyl-Cl and dabsyl-Cl have widely been used for analytical labeling through amino group. A comparison of features of off- and on-line pre- and post chromatographic/electrophoretic labeling is given using 1,2-naphthoquinone-4-sulfonate (NQS) as an example. The evaluation of the influence of the wine sample composition on the derivatization process indicates that pre-column labeling may undergo more severe matrix effects.

Contents

1. Introduction

Biogenic amines (BAs) occur naturally in a wide variety of protein-rich foods including fish, meat, vegetables, fruits and fermented foodstuffs such as dairy products, beer and wine [1,2]. BAs are formed from the degradation of the amino acids by the action of microorganisms. Spoiled food or products obtained under deficient sanitary conditions typically contain high levels of BAs, especially histamine, tyramine, putrescine and cadaverine [3]. As a result, BAs are considered as indicators of alteration and putrefaction processes.

In the case of wines, the presence of high amounts of amines may be responsible for undesirable toxicological and organoleptic effects. It has been pointed out elsewhere that monoamines such as histamine and tyramine may cause symptoms similar to allergic reactions, including cutaneous, gastrointestinal, cardiac and nervous effects [4–6]. Hence, wines with too high levels of BAs may be harmful and poisoning episodes on susceptible individuals may occasionally appear [7]. Apart from toxicological issues, diamines such as putrescine and cadaverine seem to modify negatively the taste properties of wines as they have been associated to dirty and rancid flavors [8].

Contents of BAs in wines are dependent on climatic and geological factors of the producing regions as well as enological practices (e.g., grape variety, skin maceration, microorganism strains, aging process) [8–13]. Amines are already found at low concentrations in grapes and must [14]. However, the alcoholic fermentation by

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yeasts, the malolactic fermentation by lactic bacteria and the wine aging in barrels have been identified as the principal winemaking processes contributing to the occurrence of BAs [15–17]. Various studies and surveys dealing with amine contents in different regions and countries are given in Refs. [18–25]. An important challenge of modern wine industry is the development of technologies for minimizing the amine generation. Putrescine is, by far, the most abundant BA, with levels from 5 to 60 mg L^{-1} approximately, which correspond to about a 50% of the overall amine content in wines [25]. Histamine and tyramine are generally found at concentrations in the range 1–10 mg L^{-1}. Other amines such as phenylethylamine and cadaverine usually occur at concentrations below 1 mg L^{-1}.

The relevance of sensory and toxicological implications of BAs has contributed to the proliferation of analytical methods to quantify these compounds in wines. Various revision papers have been published recently on this topic [25–28]. Typically, the determination of BAs in wines and other food matrices relies on liquid chromatography. Other separation techniques such as gas chromatography (GC) and capillary electrophoresis (CE) have been used sometimes to establish alternative methods [27,29,30]. Enzymatic procedures and immunoassays have also been exploited for implementing rapid tests of histamine or tyramine. Nowadays, commercial kits are already available for routine control of winemaking processes [31]. Apart from the quantification of individual amines, a generic biogenic amine index (BAI) has been proposed as an indicator of food freshness or spoilage [32].

Since most of BAs display poor molecular features to be detected with spectroscopic techniques (e.g. low UV–vis absorption or native fluorescence), HPLC and CE methods often include a labeling step to enhance the sensitivity. Derivatization reactions occur via amino group, being ninhydrin, o-phthaldialdehyde (OPA), 9-fluorenylmethylchloroformate (FMOC), dabsyl chloride (dabsyl-Cl) and dansyl chloride (dansyl-Cl) some of the most popular agents [25–27] suitable for spectrophotometric and fluorimetric detection. Recent advances on hyphenation between HPLC and mass spectrometry (MS) have contributed to the development of new powerful methods for wine analysis. In this case, although underivatized amines are detectable directly by MS, HPLC–MS methods often include a derivatization step for facilitating the separation and improving detection features (see applications in Table 1).

Sample pretreatment procedures to be used in the determination of amines in wines may be simpler than those required for other food matrices [33]. The addition of polyvinylpyrrolidone particles to the wine samples results in a convenient manner of removing polyphenols. The resulting faded wines can be filtered and they are ready to be used in further derivatization of amines. Solid phase extraction (SPE) with anion-exchange, reversed-phase C_{18} and polymeric cartridges are sometimes used for clean-up and pre-concentration of raw amines prior to derivatization. Liquid–liquid extraction with organic solvents may also be considered to recover either raw amines or derivatives free of polar matrix components. Various examples are given in Table 1.

In this paper, the derivatization of BAs is revised as a relevant step in the development of HPLC and CE methods for wine analysis. Almost a 90% of applications are based on off-line precolumn in which the resulting derivatives are injected into the chromatograph or the capillary electrophoresis. Online pre-column labeling in continuous-flow systems coupled to the chromatographic instrument has been seldom exploited although various successful methods have been reported in the literature using OPA and 1,2-naphthoquinone-4-sulfonate (NQS) (see Table 1). Beyond the primary role of derivatizations to enhance sensitivity, the relevance of the precolumn approach to facilitate the chromatographic separation should not be underestimated. In general, amine derivatives can be efficiently separated by reversed-phase chromatography and, furthermore, elution conditions are easily adaptable to MS detection. Post-column derivatization has been proposed for circumventing drawbacks associated to pre-column modes dealing with, for instance, the completeness of the reaction and stability of reagent and derivatives.

2. Derivatization methods for the determination of biogenic amines in wines

Table 1 shows a list of recent applications of derivatizations of BAs to wine analysis. Most of the cited derivatization reactions are analogous to those described in the literature for the determination of BAs in other food products [27,34,35]. However, differences in the pretreatment/derivatization conditions in the methods for wine and food analysis may arise. In the case of wines, the pretreatment is often simplified to filtration prior to labeling. Such a straightforward procedure can be also applied to other beverages such as beers and liquors. In contrast, for food products with higher matrix complexity (e.g., fish, cheese, chocolate, honey, vegetables, cured meets), additional cleanup processes may be required. For instance, lixiviation of solid matrices with mineral (HCl and $HClO_4$) and organic acids (CCl_3COOH and CH_3SO_3H) has been used to recover the analytes from the food samples [33,36–38]. Extracts can be then treated by sonication and centrifugation to obtain clean supernatants [39,40]. Further sample re-extraction in basic medium with organic solvents such as chloroform and diethyl ether has been also applied for analyte preconcentration and cleanup [27]. Alternatively, extracts can be purified by SPE with C_{18} or ion-exchange cartridges, liquid-phase microextraction [39] and ultrasound-assisted dispersive liquid–liquid microextraction [41]. The lixiviate/extract purification is of great importance to avoid interferences from amino acids on the derivatization step as they remain unextracted. As most of derivatization reactions take place out under basic pH conditions (from 8 to 12), when dealing with acid lixiviates, they have to be neutralized prior to derivatization. In the case of organic extracts, they can be evaporated to dryness and redissolved in the reaction buffer solution to be ready for the reaction. It should be noted that, in the case of wines, the absence of strong acid conditions facilitates the development of the reaction.

The possibilities of implementing pre- or post-column derivatization methods strongly depend on the characteristics of the reaction (e.g., experimental conditions, rate, yield and stability of reagent and derivatives). Some general shortcomings to be considered comprise the presence of reagent excess and side reaction products that may interfere with by the analytes, the lack of quantitative reactions and the formation of unstable derivatives. Labeling agents requiring long reaction times, drastic temperature conditions or time-consuming procedures for removal of the reagent excess can be exploited in off-line procedures. However, they are hardly applicable to online derivatizations since the total development of the reaction or the effective removal of reagents is difficult to achieve. Unstable derivatives or incomplete reactions can be utilized in post-column systems although they are not appropriate for pre-column procedures.

In pre-column derivatization modes, components of the wine matrix, side reaction products and reagent excess may produce interfering peaks that should be removed. As a result, a post-reaction clean-up step may be required to obtain cleaner chromatograms, especially with UV–vis and fluorescence detection. In HPLC–MS methods, these interferences may be avoided from a specific monitoring of selected ions and, thus, clean-up operations may be minimized or suppressed.

The on-line post-column derivatization step minimizes the sample manipulation while avoiding drawbacks due to the formation of several polyamine derivatives or incomplete reactions. Unfortunately, the post-column set-up may worsen the chromatographic

Table 1
Chromatographic/electrophoretic methods for the determination of biogenic amines in wines.

Reagent	Derivatization mode	Analytes	Sample treatment	Separation technique	Detection	Remarks	Ref.
OPA/2-ME	Offline precolumn Reagent: 0.1% OPA + 0.2% 2-ME + 0.05 M $B_4O_7^{2-}$ (pH 10.5); room temperature, 99 s	Him, Tym, methylhim, $MeNH_3$, $EtNH_3$, Tryp, Pea, Put, Cad	–	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 0.05 M NaAc + THF (96:4, v/v); solvent B: MeOH; flow rate: 1.2–1.5 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em,}$ 340/420 nm	LOD <0.12 mg L^{-1}; recovery: >90%	[48]
OPA/2-ME	Offline precolumn Reagent: 0.7% OPA + 5% 2-ME + 0.4 M H_3BO_3/BO_2^- (pH 10.5)	Him, $MeNH_3$, $EtNH_3$, Tym, Pea, Put, Cad	–	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 10 mM Na_2HPO_4; solvent B: 1% 2-octanol in ACN + solvent A (70:30, v/v); flow rate: 0.8 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em,}$ 340/425 nm	LOD: 0.006–0.06 mg L^{-1}; recovery: 88–118%	[49]
OPA/3-MPA	Offline precolumn Reagent: OPA + 3-MPA + 0.1 M H_3BO_3/BO_2^- (pH 9.3)	Him, $MeNH_3$, Agm, $EtNH_3$, Tym, Pea, Put, ethanolamine, Cad, *n*-butylamine, *i*-butylamine, *n*-propylamine, *i*-propylamine, isoamylamine	–	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 0.05 M NaAc (pH 7.2); solvent B: 0.05 M NaAc (pH 7.2) + ACN + MeOH (40:45:15); flow rate: 1 mL min^{-1}	UV absorption 335 nm Fluorescence $\lambda_{ex}/\lambda_{em}$, 337/454 nm	RSD <4%	[50]
OPA/2-ME	On-line pre-column Reagent: 0.024% OPA + 0.002% ME + 0.4 M H_3BO_3/BO_2^- (pH 10.5) 0.075 mL min^{-1}	Him, $MeNH_3$, $EtNH_3$, Tym, Spd, Pea, Put, Cad, isoamylamine	Online SCX precolumn Sample: 980 μL Elution sent to derivatization system	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 20 mM H_3BO_3/BO_2^- (pH 8.2); solvent B: ACN/1-octanol; flow rate: 0.35 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 350/445 nm	LOD: <0.05 mg L^{-1}; precision (RSD): 2.2–15.9%	[51]
OPA/2-ME	Post-column Reagent: OPA + 2-ME + H_3BO_3/BO_2^- (pH 10.5); flow rate: 0.5 mL min^{-1}	Tym, Put, Cad, Him, Agm, Pea, Spd	–	Ion pair HPLC (C_{18}) Elution gradient: solvent A: 0.1 M NaAc (pH 4.5) + 10 mM SOS; solvent B: 0.2 M NaAc (pH 4.5) 10 mM SOS/ACN (10:3, v/v); flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em,}$ 345/445 nm	Precision (RSD): 0.4–6.7%	[52]
OPA/2-ME	Post-column Reagent: 0.2% OPA + 0.3% 2-ME + H_3BO_3/BO_2^- (pH 10.5); flow rate: 0.4 mL min^{-1}; temperature: 40 °C	Octm, Dpm, Tym, Put, Cad, Sem, Him, Agm, Pea, Spm, Spd, Tryp	–	Ion pair HPLC (C_{18}) Elution gradient: solvent A: 0.1 M NaAc (pH 5.3) + 10 mM SOS; solvent B: 0.2 M NaAc (pH 4.5) 10 mM SOS/ACN; flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 340/445 nm	LOD: 0.03–0.06 mg L^{-1}; recovery: 98–101%	[53]
OPA/2-ME	Post-column Reagent: OPA + 2-ME; flow rate: 0.8 mL min^{-1}	Put, Cad, Tym, *i*-butylamine, Him, 2-methyl-butylamine Agm, 3-methyl-butylamine *n*-pentyl-amine, Spd, Pea, Tryp, Spm	–	Ion-pair HPLC (C_{18}) Elution gradient: solvent A: 0.165 M NaAc (pH 5.25) + 10 mM SOS; solvent B: 0.2 M NaAc (pH 4.5) 10 mM SOS/ACN (34:66); solvent C: 0.01 M NaAc (pH 5.25) + 10 mM SOS; flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 345/445 nm	LOD: 0.002–0.1 mg L^{-1}; recovery: 93–101%	[54]
OPA/2-ME	Post-column Reagent: 0.2% OPA + 2-ME + H_3BO_3/BO_2^- (pH 10.5); flow rate: 0.4 mL min^{-1}; temperature: 42 °C	Dpm, Tym, Pur, Sem, Cad, Him, Agm, Pea, Spm, Tryp, Spd	–	Micellar UHPLC Elution gradient: solvent A: 0.1 M NaAc (pH 4.8) + 10 mM SOS; solvent B: 0.2 M NaAc (pH 4.5) + 10 mM SOS + ACN (6.6:3.4),	Fluorescence $\lambda_{ex}/\lambda_{em}$, 340/445 nm	Separation of 12 amines in less that 7 min; LOD: <0.2 mg/L	[55]
OPA/*N*-acetylcysteine	On-column: see solvent B	$MeNH_3$, $EtNH_3$, Him, Tym, Put, Cad, Pea, methylbutamine	SPE with SAX and C_{18} cartridges	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 5 mM borate solution (pH 9) + 1% THF; solvent B: 5 mM borate solution (pH 9) + 12 mM OPA-NAC; solvent C: ACN; flow rate: 0.8 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 340/450 nm	LOD: 0.1–0.3 mg L^{-1}; PE (%) <5%	[56]

Table 1 (*Continued*)

Reagent	Derivatization mode	Analytes	Sample treatment	Separation technique	Detection	Remarks	Ref.
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + Na_2CO_3 (pH 7.8); 40 °C, 1 h	Cad, Put, Him, Tym, Tryp, Agm, isoamylamine $MeNH_3$, ethanolamine	PVP adsorption: 15 min	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: H_2O; solvent B: ACN; flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 320/523 nm	LOD: <0.18 mg L^{-1}; recovery: >85%	[57]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + H_3BO_3/BO_2^- (pH 10); 65 °C, 25 min Post-derivatization: SPE C_{18}	Ethanolamine, Cad, Put, Him; Tym, Tryp, Agm, $MeNH_3$, Spm, Spd	–	Reversed-phase nano-HPLC (C_{18}) Elution gradient: solvent A: ACN/0.23% TEA (pH 5) 10/90 (v/v); solvent B: ACN/0.23% TEA (pH 5) 90/10 (v/v); flow rate: 634 nL min^{-1}	UV absorption 250 nm	LOD: 18–48 ng mL^{-1}; recovery: 30–95%	[58]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + H_3BO_3/BO_2^- (pH 9.5); 65 °C, 30 min Post-derivatization: SPE C_{18}	$MeNH_3$, $EtNH_3$, ethylamine, Pea, isoamylamine, Put, Cad, Tym, Him, Spm, Spd	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: H_2O; solvent B: ACN; flow rate: 1 mL min^{-1}	UV absorption 254 nm	Recovery: 70–106%	[59,60]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + H_3BO_3/BO_2^- (pH 9.5); 65 °C, 30 min Post-derivatization: SPE C_{18}	$MeNH_3$, $EtNH_3$, Pea, isoamylamine, Put, Cad, Tym, Him, Spm, Spd	PVP adsorption: 15 min	Reversed-phase HPLC C_{18} Elution gradient: solvent A: H_2O; solvent B: ACN; flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 320/523 nm	Precision (RSD) 1.0–5.9%	[61]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + H_3BO_3/BO_2^- (basic pH) Post-derivatization: LLE diethyl ether, evaporation; MeOH redissolution	Tryp, Pea, Put, Cad, Him, Tym, Spd, Spm,	LLE *n*-ButOH/CCl_3H, solvent evaporation; 0.1 M HCl redissolution	Reversed-phase HPLC C_{18} Elution gradient: solvent A: H_2O; solvent B: MeOH; flow rate: 1.5 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 350/520 nm	LOD: 0.06–0.2 mg L^{-1}; recovery: 85–127%	[19]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + Na_2CO_3 (pH 8.2); 40 °C, 60 min	Cad, Put, Him, Tym, Tryp, Pea, Spd, Spm, ethanolamine, 1,7-diaminoheptane, o-methyl-hydroxylamine	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: water; solvent B: ACN; flow rate: 0.4 mL min^{-1}	UV absorption 254 nm	LOD: 0.01–0.02 mg L^{-1}; recovery: 85–98%	[62]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + Na_2CO_3 40 °C, 30 min; reagent removal: glutamine at 40 °C, 60 min	Tryp, Pea, Put, Cad, Him, Tym, Spd, Spm, Agm	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: TRIS (pH 8), ACN (45/55, v/v); solvent B: TRIS (pH 8)/ACN (10/90, v/v); flow rate: 1.3 mL min^{-1}	UV absorption 220 nm	–	[25]
Dns-Cl	Off-line precolumn 1% Dns-Cl + sample + H_3BO_3/BO_2^- (pH 9.5); 65 °C, 30 min Post-derivatization: SPE C_{18} elution with ACN, evaporation; ACN redissolution	$MeNH_3$, $EtNH_3$, Put, Cad, isoamylamine Tym, Spm, Spd, Tryp, Pea	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: H_2O; solvent B: ACN; flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 320/523 nm APCI-MS range m/z: 100–1300 amu	LOD: <0.008 mg L^{-1}; recovery: 73–114%	[63]
Dbs-Cl	Off-line precolumn 12 mM Dbs-Cl + sample + 2% Na_2CO_3 (pH 8.2); 70 °C, 21 min	Tryp, Pea, Spm, Spd, Him, Cad, Put, Tym,	Online SLM [45] Acceptor: 0.1 HCl Donor: HAc/NaAc (pH 5) Membrane: PTFE with TEHP + DHE + DEHPA	Reversed-phase HPLC C_{18} Elution gradient: solvent A: 40 mM NaAc, 10% DMF (v/v), 0.23% TEA (v/v) (pH 5.0); solvent B: 87.5% ACN, 10% TBME + 2.5% water (v/v/v); flow rate: 1 mL min^{-1}	UV absorption 446 nm	LOD: 0.1–0.6 mg L^{-1}; prediction error: 2.8–11.7%	[64–66]

Table 1 (*Continued*)

Reagent	Derivatization mode	Analytes	Sample treatment	Separation technique	Detection	Remarks	Ref.
FMOC	Off-line precolumn 0.8% FMOC + sample + H_3BO_3/BO_2^- (pH 8.5); 25 °C, 3 min FMOC excess removal: 0.55 M NH_4^+	Put, Spm, Spd, Agm	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: ACN + 2-octanol (100/1); solvent B: ACN + H_3PO_4 + DMCHA + water (150/5/10/835); flow rate: 0.7 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 263/313 nm	Repeatability: 1.6–13.6%	[67,68]
Fmoc-OSu	Off-line precolumn 3 mM FMOC-OSu + sample + 0.5 M Na_2CO_3/HCO_3^- (pH 10.2); 25 °C, 20 min	Amino acids + Put, Cad, Spm, Spd	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: 5 mM dibutylamine (pH 2.20) + 5% ACN (v/v); solvent B: 95/5% (v/v), ACN/solvent A; flow rate: 1.5 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 262/630 nm	LOD: <0.3 μg L^{-1}; repeatability: 1.1–6.7%	[69]
OPA/FMOC	Off-line precolumn Step 1: OPA derivatization: reagent (3.5% OPA + 3MC + KCN) + sample + 0.4 M H_3BO_3/BO_2^- (pH 10.4); 25 °C, 2.5 min Step 2: FMOC derivatization: FMOC + sample + 0.4 M H_3BO_3/BO_2^- (pH 10.4); 25 °C, 2 min	Amino acids + ethanolamine; Him, Tym, $MeNH_3$, $EtNH_3$, Tym, Put, Cad, Pea, Tryp, isoamylamine	–	Reversed-phase HPLC C_{18} Elution gradient: solvent A: 20 mM NaAc + 0.018%TEA + 0.3% THF + 4% EDTA (pH 7.2); solvent B: 20% NaAc + 40% ACN + 40% MeOH 0.018% TEA; flow rate: 0.5–1.2 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 340/450 nm (primary amino groups), $\lambda_{ex}/\lambda_{em}$, 237/340 nm (secondary amino groups)	LOD: 0.3 mg L^{-1}; recovery: 81–138%	[70–72]
DEEMM	Off-line precolumn DEEMM + sample + 1 M H_3BO_3/BO_2^- (pH 9); 25 °C, 30 min; reagent degradation: 70 °C, 2 h	Amino acids + Him, Agm, Spd, Tym, Put, Tryp, Cad, Pea, isoamylamine.	–	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 20 mM NaAc (pH 5.8) + 0.02% NaN_3; solvent B: ACN/MeOH 80/20 (v/v); flow rate: 0.9 mL min^{-1}	UV absorption 269, 280 and 300 nm	LOD < 0.06 mg L^{-1}; recovery: 95–105%	[73]
NOC-Cl	Off-line precolumn 5 mM NOC-Cl + sample + 0.5 M H_3BO_3/BO_2^- (pH 9); 25 °C, 3 min; reagent removal: 20 mM glycine	Him, Spd, Tym, Put, Cad, Pea, Spm	–	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 100 mM NaAc (pH 4.4); solvent B: ACN; flow rate: 1.5 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 274/335 nm	LOD: 80–190 μg L^{-1}; recovery: 65–109%	[74]
SAMF	Off-line precolumn 1 mM SAMF + sample + H_3BO_3/BO_2^- (pH 8); 20 °C, 6 min	Ethanolamine, $MeNH_3$, $EtNH_3$, *n*-propylamine, *n*-butylamine, *n*-pentylamine *n*-hexylamine	–	Reversed-phase HPLC: C_{18} Isocratic elution: solvent: citrate buffer; flow rate: 0.7 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 484/516 nm	LOD: 2–320 fmol; recovery: 95–106%	[75]
TMPAB-OSu	Off-line precolumn 2 mM TMPAB-OSu + sample + H_3BO_3/BO_2^- (pH 8.5); 45 °C, 5 min	Spm, Pea, Spd, Put, Cad,	–	Reversed-phase HPLC: C_8 Isocratic elution: solvent: NaAc (pH 5.8, 1% THF) + methanol (27:73, v/v); flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 497/509 nm	LOD: 0.1–4 nmol L^{-1}; recovery: 95–102%	[76]
BC	Off line pre-column 10 min at 25 °C at basic pH (0.1 M NaOH); extraction of derivatives: diethyl ether; solvent evaporation redissolution in MeOH	$MeNH_3$, Put, Cad, Trpm, Pea, Spd, Spm, Him, Tym, Agm	–	Reversed-phase HPLC (C_{18}) Elution gradient: solvent A: 0.05 M NaAc + MeOH 60:40; solvent B: MeOH	UV absorption 254 nm	LOD: 0.2–2.5 mg L^{-1}; recovery: 72.8–103.4%	[77]
BC	On-column SPE derivatization: BC + sample + 2 M NaOH through the SPE cartridge	Trpm, Pea, Put, Cad, Spd, Spm, Him, Tym, Agm	Combination SPE + derivatization	Micellar HPLC Elution gradient: solvent A: 0.02 M H_3PO_4 (pH 3.0) + 0.40 M SDS; solvent B: ACN; flow rate: 1.1 mL min^{-1}	UV absorption 254 nm	LOD: 0.1 μg L^{-1}; recovery: 94–106%	[78]
AQC	Offline pre-column Boric/borate buffer (pH 8.8)	Him, Put, Tym, Cad	SPE (mixed-mode SCX and C_{18})	Reversed-phase HPLC: C_{18} Elution gradient: solvent A: 140 mM NaAc + 17 mM TEA (pH 5.05); solvent B: MeOH	Fluorescence $\lambda_{ex}/\lambda_{em}$, 250/395 nm	LOQ <0.16 mg L^{-1}; Tym recovery was less than 70%	[79,80]

Table 1 (*Continued*)

Reagent	Derivatization mode	Analytes	Sample treatment	Separation technique	Detection	Remarks	Ref.
AQC	Off line pre-column Boric/borate buffer	Amino acids + Him, Put, Tym, Cad	–	Reversed-phase HPLC: C_{18} silica column Solvent A: 140 mM NaAc + 17 mM TEA (pH 5.05); solvent B: MeOH	Fluorescence: $\lambda_{ex}/\lambda_{em}$, 250/395 nm	LOQ <0.16 mg L^{-1}; recovery: <70% for Tym	[81]
AQC	Off line pre-column 10 mM AQC + sample + boric/borate buffer	$MeNH_3$, $EtNH_3$, Him, Pea, Tym, Put, Cad, 3-methylbutylamine	SPE by SCX Elution: 75 mM $B_4O_7^{2-}$/MeOH 50% (v/v)	Reversed-phase HPLC: C_{18} Elution gradient: solvent A: 50 mM NaAc + 1% THF; solvent B: MeOH; flow rate: 1.0 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 250/395 nm	LOD: 20–100 μM; precision (RSD) 3.9–8.7%	[82]
FBQCA	Off-line precolumn Sample + 10 mM FBQCA; μL of working 0.2 M cyanide solution The mixture was incubated at 40 °C for 45 min in the dark	Ethanolamine $MeNH_3$, $EtNH_3$, *n*-propylamine, *n*-butylamine, *n*-pentylamine, *n*-hexylamine, *n*-heptylamine, *n*-octylamine, *n*-nonylamine, *n*-decylamine	–	Reversed-phase HPLC: C_8 Solvent A: H_2O; solvent B: MeOH (25:75, v/v); flow rate: 1 mL min^{-1}	Fluorescence $\lambda_{ex}/\lambda_{em}$, 380/546 nm	LOD: 0.5–2 nm; recovery: 94–106%	[83]
PNZ-CI	25 mM PNZ-CI + sample + 0.5 M borate buffer (pH 9.0); 25 °C for 10 min; reagent removal: 0.2 m glycine	Him, Put, Tym, Pea, octopamine, cad Trpm, Sem, Spd, Spm	–	Reversed-phase HPLC: C_{18} Solvent A: 10 mM NaAc (pH 6.1); solvent B: 10 mM NaAc (pH 4.3); solvent C: ACN; flow rate: 0.8–1.3 mL min^{-1}	UV absorption 265 nm	LOD: 62–1000 μg L^{-1}; precision (RSD): 2.1–9.9%	[84]
NQS	Off-line precolumn 70 mM NQS + sample + 0.125 M H_3BO_3/BO_2^- (pH 9.2); 65 °C, 5 min; LLE $CHCl_3$ evaporation redissolution MeOH	Him, Put, Cad, Tym, Tryp, Sem, ethanolamine Pea	–	Reversed-phase HPLC: C_{18} Solvent A: 2% HAc; solvent B: MeOH; flow rate: 0.8–1.3 mL min^{-1}	UV absorption 270, 305 nm APCI-MS, monitoring specific ions	LOD (UV): 0.006–0.31 mg L^{-1}; LOD (MS): 0.17–2.5 μg L^{-1}; recovery: 82.5–110.0%	[85–87]
NQS	Online continuous flow precolumn 60 mM NQS; sample 0.05 M H_3BO_3/BO_2^- (pH 9.5); flow rate: 0.33 mL min^{-1} each channel; 80 °C, ~2.9 min	Him	–	Reversed-phase HPLC: C_{18} Solvent A: 2% HAc; solvent B: MeOH; flow rate: 0.8–1.3 mL min^{-1}	UV absorption 305 nm	LOD: 0.22 mg L^{-1}; recovery: 101.1–110.0%	[88]
NQS	Post-column 4 mM NQS 25 mM H_3BO_3/BO_2^- (pH 9.5); flow-rate: 0.4 mL min^{-1}; temperature: 75 °C	Agm, Trpm, Cad, Pea, Him, Sem, Put, Tym, Spm, Spd, Dpm, ethanolamine	–	Ion-pair HPLC (C_{18}) Elution gradient: solvent A: 15% ACN + 85% aqueous solution (15 mM SHS + 10 mM H_3PO_4); solvent B: 70% ACN + 30% aqueous solution (8 mM SHS + 10 mM H_3PO_4); flow rate: 0.8 mL min^{-1}	UV absorption 305 nm	LOD: 0.2–3 mg L^{-1}; recovery: 92–108%	[89]
NQS	In-capillary in mixed tandem mode reagent/buffer/sample 60 mM NQS	Agm, Trpm, Cad, Pea, Him, Sem, Put, Tym	–	CE Fused-silica capillary (59 cm × 75 μm I.D.); voltage: 30 kV (90 μA); buffer: 40 mM $Na_2B_4O_7$ (pH 10.5)-2-propanol (25%, v/v)	UV absorption 270, 305 nm	LOD: 0.02–0.9 mg L^{-1}; recovery: 89–111%	[90]
OPA/2-ME	Off-line precolumn 16 mM OPA + sample + H_3BO_3/BO_2^- (pH 10.7); 40 °C, 30 min; reagent removal: glutamic acid	Him, Tym, Agm $MeNH_3$, $EtNH_3$, Trpm, Pea, Put, Cad	–	Cyclodextrin-modified CE Fused-silica capillary (40 cm × 50 mm I.D.); voltage: 20 kV; running buffer: 15 mM borate (pH 9.0) + 10% EtOH + 15 mM HPCD + 25 mM SBCD	UV absorption 214 nm LIF $\lambda_{ex}/\lambda_{em}$, 325/450 nm	LOD: 0.25 μM	[91]

Table 1 (*Continued*)

Reagent	Derivatization mode	Analytes	Sample treatment	Separation technique	Detection	Remarks	Ref.
FITC	0.2 mM FITC + 0.2 m carbonate buffer (pH 9.0) + sample 2 h in darkness	Amino acids + β-Pea, Put Tym Spd, $MeNH_3$, ethanolamine	–	MEKC Silica capillary 42 cm × 50 μm I.D.; running buffer: 20 mM SDS + 100 mM boric acid, pH 9.3; potential: 20 kV	LIF λ_{ex} 488 nm	–	[92]
AQC	Off line pre-column 10 mM AQC + sample + boric/borate buffer; 55 °C, 10 min	Him, Put, Tym, Cad, Trpm, Spm, Spd	–	MEKC Silica capillary: 30 cm × 50 μm; running buffer: 100 mM boric acid, 50 mM SDS and 10% ACN (pH 8.9); potential: 15 kV	UV absorption 254 nm	LOD: 1–40 μM; precision (RSD) 3.3–4.9%	[93]
FBQCA	Sample + 10 mM FBQCA 30 μL of working 0.2 M cyanide solution The mixture was incubated at 50 °C for 20 min in darkness	Him, Tym, Pea, Put, Cad, Spm, Spd	–	MEKC Buffer: 25 mM boric acid (pH 9.5), 25 mM SDS, and 27% ACN; at 25 °C, 22.5 kV	LIF $\lambda_{ex}/\lambda_{em}$, 488/520 nm	LOD: 0.4 nm	[94]
FS	Off-line precolumn 1 mM FS + sample + Na_2CO_3 (pH 10.4); 25 °C, 15 min	Him, Tym	–	Portable microchip CE Running buffer: 8 mM Na_2CO_3 (pH 10.4); potential: 15 kV	Fluorescence $\lambda_{ex}/\lambda_{em}$, 400/all nm	120 s separation	[95]
ECF + PFPA	ECF + sample + NaOH (pH 12) LLE diethyl; LLE ethyl acetate PFPA derivatization: 60 °C, 30 min; LLE diethyl ether + ethyl acetate	Polyphenols + amines	–	Capillary GC DB-17 MS (OV-17 bonded) fused-silica capillary Temperature: 60–290 °C	MS 50–700 amu	LOD: 1–70 ng PE <10%	[96]
HFBA	Off-line precolumn HFBA 80 °C, 60 min Extraction with CH_2Cl_2 solvent evaporation redissolution in ethyl acetate	Pea, Put, Cad, Tym Spd, Spm	LLE Sample + KOH + BEHPA in CCl_3H Back extraction 0.1 M HCl evaporation	GC DB-5 MS capillary column (30 m × 0.25 mm I.D., 0.25 μm film thickness); gradient: 80–290 °C	MS: 50–700 amu Monitoring characteristic ions of each derivative	LOD: 10 μg L^{-1}; recovery: 74–120%	[97]
PFB	Off-line precolumn 10 mg L^{-1} PFB in ACN pH 12; 20 °C, 30 min	$MeNH_3$, $EtNH_3$, *n*-propylamine *n*-butylamine, *n*-pentylamine *n*-hexylamine *n*-heptylamine, Pea, Put, Cad	PVP adsorption LLE with hexane	GC 30 m × 0.25 mm I.D. × 0.25 μm film DB-5 capillary column; gradient: 45–280 °C	MS full scan (*m*/*z* 50–500) for ion selection and SIM (*m*/*z* 208.0, 211.0, and 213.0)	Recovery: 81–100%	[98]

ACN, acetonitrile; Agm, agmatine; APCI, atmospheric pressure chemical ionization; AQC, aminoquinolyl-*N*-hydroxysuccinimidylcarbamate; BC, benzoyl chloride; BEHPA, bis-2-ethylhexylphosphate; Cad, cadaverine; Dbs-Cl, dabsyl-Cl; DEEMM, diethylethoxymethylenemalonate; DEHPA, di-2-ethylhexylphosphoric acid; DHE, di-*n*-hexyl ether; DMCHA, *N*,*N*-dimethylcyclohexylamine; DMF, dimethylformamide; Dns-Cl, dansyl-Cl; Dpm, dopamine; ECF, ethylchloroformate; $EtNH_3$, ethylamine; FBQCA, 3-(4-fluorobenzoyl)-2-quinolinecarboxaldehyde; FITC, fluoresceinisothiocyanate; FMOC, fluorenylmethylchloroformate; Fmoc-OSu, *N*-(9-fluorenylmethoxycarbonyloxy)succinimide; FS, fluorescamine; GC, gas chromatography; HAc, acetic acid; HFBA, heptafluorobutyric anhydride; HPCD, hydroxypropyl-β-[22]cyclodextrin; HPLC, high performance liquid chromatography; Him, histamine; LIF, laser-induced fluorescence; LLE, liquid–liquid extraction; LOD, limit of detection; LOQ, limit of quantification; 3-MC, 3-mercaptocysteine; 2-ME, 2-mercaptoethanol; MECK, micellar electrokinetic chromatography; $MeNH_3$, methylamine; MeOH, methanol; 3-MPA, 3-mercaptopropionic acid; MS, mass spectrometry; NAC, *N*-acetyl cysteine; NaAc, sodium acetate; NOC-Cl, 2-naphthyloxycarbonyl chloride; NQS, 1,2-naphthoquinone-4-sulfonate; OPA, o-phthaldialdehyde; PE, prediction error; Pea, phenylethylamine; PFB, pentafluorobenzaldehyde; PFPA, pentafluoropropionyl anhydride; PNZ-Cl, p-nitrobenzyloxycarbonyl chloride; PTFE, polytetrafluoroethylene; PVP, polyvinylpyrrolidone; Put, putrescine; RSD, relative standard deviation; SAMF, 6-oxy-(*N*-succinimidyl acetate)-9-(2-methoxycarbonyl)fluorescein; SAX, strong anion exchange; SBCD, sulfobutylether-β-cyclodextrin; SDS, sodium dodecylsulfate; Sem, serotonin; SHS, sodium heptylsulfate; SIM, single-ion monitoring; SLM, supported liquid membrane (extraction); SOS, sodium octylsulfate; Spd, spermidine; SPE, solid-phase extraction; Spm, spermine; TBME, tert-butylmethyl ether; TEA, triethylamine; TEHP, tri-2-ethylhexylphosphate; THF, tetrahydrofurane; TMPAB-OSu, 8-phenyl-(4-oxy-acetic acid *N*-hydroxysuccinimide ester)-4,4-difluoro-1,3,5,7-tetramethyl-4-bora-3a,4a-diaza-s-indacene; TRIS, Tris-(hydroxymethyl)aminomethane; Trpm, tryptamine; Tym, tyramine; UHPLC, ultra high performance liquid chromatography.

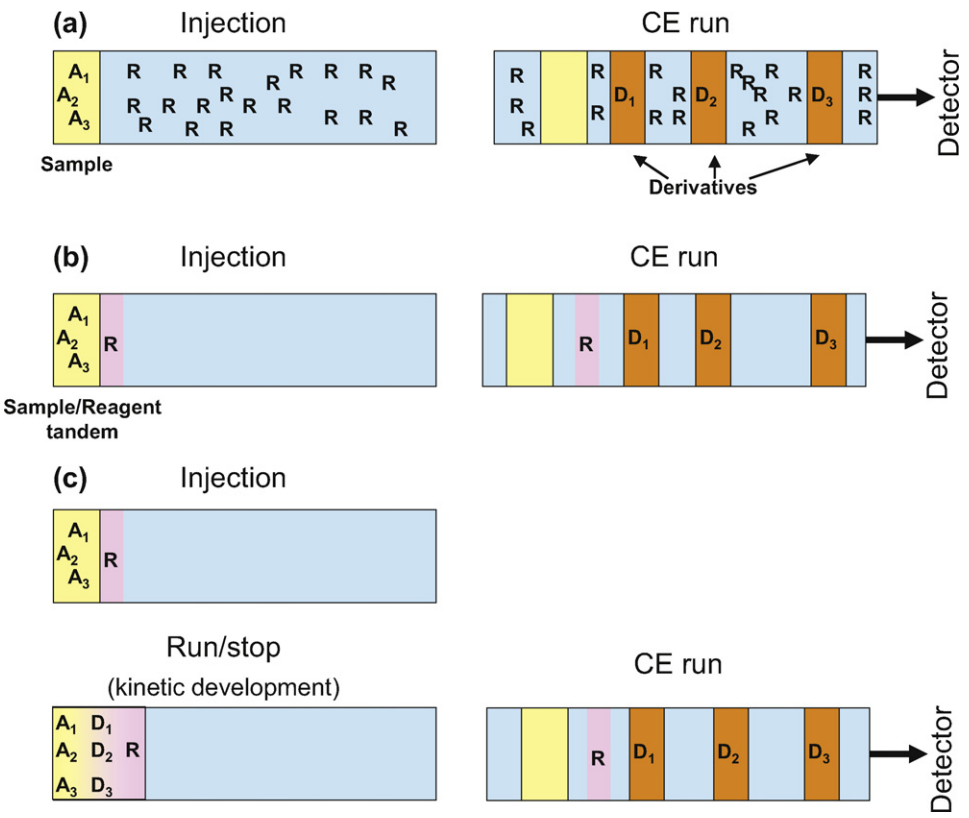

Fig. 1. In-capillary derivatization estrategies in CE. (a) Throughout mode, reagent added to the running buffer; (b) zone-passing mode, sample and reagent segments injected into the capillary and (c) at-inlet, kinetic development of the reaction by stopping the CE run after sample and reagent injection, CE run is restarted after stopping time. R, reagent; A_1, A_2 and A_3, analytes present in the sample; D_1, D_2 and D_3, derivatives formed from analytes A_1, A_2 and A_3, respectively.

resolution as well as the detection limits due to the additional dispersion of analytes inside the derivatization system.

The application of CE to quantify common dietary amines is gaining popularity due to advantages of this technique on decreasing sample and reagent consumption and analysis time. Some of the labeling agents utilized in HPLC have been readapted to CE analysis (see Table 1). In the case of wines, detection limits reached in these methods are fully compatible with the typical levels of BAs. Furthermore, recent advances in derivatization strategies and innovative on-line pre-concentration procedures have contributed to enhance dramatically the sensitivity of the methods [42–45].

Various in-capillary modes and injection strategies have been considered in order to establish the optimal CE derivatization conditions (see scheme in Fig. 1): (a) throughout-capillary mode, in which the reagent is incorporated to the running buffer so the labeling occurs throughout the capillary; (b) zone-passing mode, where the reaction occurs during the CE run when mixing analytes and reagent. In this case, sample (S), buffer (B) and reagent (R) segments can be introduced into the capillary in various ways: tandem (R–S), sandwich (R–S–R), mixed tandem (R–B–S), etc; and (c) at-inlet mode, in which the reaction takes place at the inlet of the capillary and a kinetic development of the reaction for a desired time is allowed.

2.1. Strategies for the optimization of reaction conditions

The optimization of experimental conditions to carry out the derivatization often relies on searching the highest instrumental response. However, this approach may be insufficient since other important issues such as interferences, detection limits, precision, etc. should also be kept in mind. Besides, when dealing with various analytes, the optimum conditions for one of them may be different that those required for another. In these circumstances, the definition of a global criterion or objective to be optimized deserves our attention. Another point to be considered is the selection of variables that may influence on the process. In the case of derivatizations, reagent concentration, pH, temperature and time are expected to be some of the most relevant factors. Tools for facilitating the optimization based on experimental design and multicriteria approaches may be helpful [46].

An excellent way to deal with multiple objectives simultaneously is based on the definition of a response function that measures the overall suitability or quality of the experimental results. Multicriteria response functions can be implemented as mathematical expressions combining individual objectives such as in Derringer desirability functions [47]. The overall desirability D is then calculated as the geometric mean.

Screening experiments may be recommendable to evaluate the effect of factors on the derivatization. At this point, variables found relevant can be studied more exhaustively with other factorial designs to evaluate the statistical significance of effects and interactions. When interactions occur, response surface, central composite and related designs can be utilized for the simultaneous optimization of such variables.

2.2. Influence of wine matrix on the derivatization

In general, pre-column methods are more susceptible to undergo matrix effects than on-column (in-capillary) or post-column counterparts. This is because wines contain high amounts of organic acids (e.g., tartaric and malic acids) that may lead to a significant drop in the reaction pH in comparison with pure standards. In these circumstances, the reaction may be hindered

so the claimed quantitative formation of derivatives may be not achieved. This drawback could be solved using solutions with higher buffer capacity. But even this case, slight pH variations in the reaction media may occur and, thus, changes in sensitivity may appear.

Another factor that may affect the derivatization of BAs is the presence of high amounts of amino acids in the wines. Amino acid concentrations are one or two orders of magnitude higher that those of BAs. When amino acids consume a significant percentage of reagent, the amount remaining available to react with BAs will decrease. This effect could be solved experimentally using more concentrated reagent solutions. Unfortunately, for practical reasons, too high reagent concentrations are not recommendable since interferences from the excess and degradation products will increase dramatically. In pre-column methods, for instance, a 10- to 100-fold excess with respect to amino compounds may be sufficient to avoid problems dealing with quantitative derivatizations.

3. Reagents for the derivatization of amines

As given in Table 1, OPA has been utilized in both pre- and post-column procedures. OPA is able to react with primary amino groups in the presence of a mercapto compound, typically 2-mercaptoethanol, to yield derivatives detectable by UV absorption spectrophotometry (at ~215 nm) and emission fluorescence spectroscopy ($\lambda_{ex}/\lambda_{em}$, ~340–350/~420–450 nm). The reaction of amines with OPA and 2-mercaptoethanol (2-ME) takes place in basic pH (8.5–10.7) at room temperature. Some modifications have been reported such as OPA/3-mercaptopropionic reaction, readapted by Kutlan for the fluorimetric determination of amines in wines and other food matrices [50]. OPA is often used in post-column labeling in which a channel delivering the ingredients of the reaction is connected to the chromatographic eluate. In such a case, the separation is based on ion-pair or micellar chromatography using sodium dodecylsulfate (SDS) or sodium octylsulfate (SOS) as ion-pair/micellar reagents. In these cases, the amines in cationic form interact with the anionic surfactant thus resulting in aggregates that can be separated in reversed-phase columns. For instance, Vidal-Carou et al. have reported an ion-pair HPLC method for the determination of mono- and polyamines in wines by post-column derivatization [53]. In a more special case, Busto et al. have developed an on-column labeling method with fluorescence detection in which OPA is contained in the mobile phase. Then, both separation and labeling processes occur simultaneously inside the analytical column [56]. Other OPA applications rely on recent advances in chromatographic techniques such as UHPLC or nano-LC [55].

OPA is sometimes utilized in combination with FMOC which is added to derivatize secondary amino groups. This strategy has been adopted in the simultaneous determination of amines and amino acid in which FMOC is utilized to obtain proline and hydroxyproline reaction products.

Dns-Cl is another popular reagent containing sulfonyl chloride as the active group able to react with both primary and secondary amines. The reaction requires longer reaction times (20–60 min) and higher temperatures (40–70 °C) in comparison with OPA. For this reason, its use is restricted to offline pre-column methods [57–63]. Derivatives can be monitored spectrophotometrically at ~250 nm or fluorimetrically at $\lambda_{ex}/\lambda_{em}$, ~320–350/~520 nm. The intrinsic absorption or fluorescence of the reagent may cause interferences so procedures for reagent removal after labeling are recommended. For this purpose, some authors have utilized an excess of an amino acid (e.g., glutamic acid or glycine) to form a derivative which can be separated easily in the chromatographic run from those peaks of amines. Besides, SPE and liquid–liquid extraction (LLE) have also been utilized for cleanup. Once derivatives have been formed, they can be separated by reversed-phase chromatography. Dbs-Cl is another sulfonyl chloride reagent sometimes applied to amine determination. The reaction of analytes with Dbs-Cl is structurally similar to that occurring with Dns-Cl so experimental conditions are similar to those indicated for Dns-Cl [64–66].

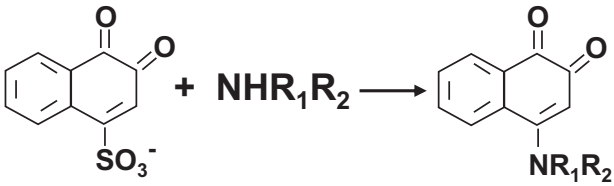

Fig. 2. Scheme of the reaction of primary and secondary amines with 1,2,-naphthoquinone-4-sulfonate in basic medium (R_1 = H for primary amines).

Other reagents that have been utilized occasionally for the analysis of BAs in wines by HPLC are given in Table 1. Pre-column derivatization procedures with chloroformates (FMOC, NOC-Cl or PZN-Cl), acyl chlorides (e.g., benzoyl chloride), carbamates (e.g., AQC), aldehydes (e.g., FBQCA) and isothiocyanates (FITC) have been utilized in combination with reversed-phase separation in C_{18} or C_8 analytical columns [67–84]

Some authors have adapted the derivatization procedures to develop CE methods for the analysis of BAs. For instance, fluorescamine, AQC, FBQCA and FITC have been utilized for amine labeling according to an offline precolumn procedures [90–94]. Table 1 also includes various applications of GC to amine determination. Some of the main goals of the derivatization in GC concern the decrease of polarities and increase of volatilities [95–98].

3.1. Derivatization approaches using 1,2-naphthoquinone-4-sulfonate as a labeling agent

NQS is a general reagent for primary and secondary amino groups. As described in the literature, the derivatization is developed, in general, in basic medium (pH 8.5–10.5) at temperatures from 50 to 80 °C for reaction times from 2 to 20 min. NQS has been used previously for the pre- and post-column derivatization of amino acids [44,45,99–101] in HPLC and CE methods. More recently, NQS has been applied to the quantification of BAs in wines according to the strategies given in Fig. 3. Schemes depicted correspond to off-line and online precolumn derivatization [85–88], post-column labeling after HPLC separation of amines in micellar medium [89] and in-capillary derivatization in CE based on mixed-tandem zone-passing mode [90].

The main reaction of primary and secondary amines with NQS in basic medium consists of the nucleophilic aromatic substitution of sulfonate by the amino group, as shown in the scheme of Fig. 2. For compounds such as serotonin and tyramine, containing a phenol group that may also act as a nucleophile, both NH_2- and OH- are active so diderivatives are obtained as major components. In the case of diamines such as putrescine and cadaverine, NQS diderivatives are formed as well.

Reaction time and temperature have been found to be important variables that have been optimized simultaneously using a central composite design. In this case, the peak areas of each amine derivative have been utilized as responses. Results indicate that the best global compromise to derivatize all these analytes is attained at 65 °C for reaction time of 5 min.

The influence of matrix composition on the derivatization of BAs with NQS has been evaluated from the comparison of sensitivities of the calibration curve from pure standards with those obtained in different wines chosen as models. It has been found that the

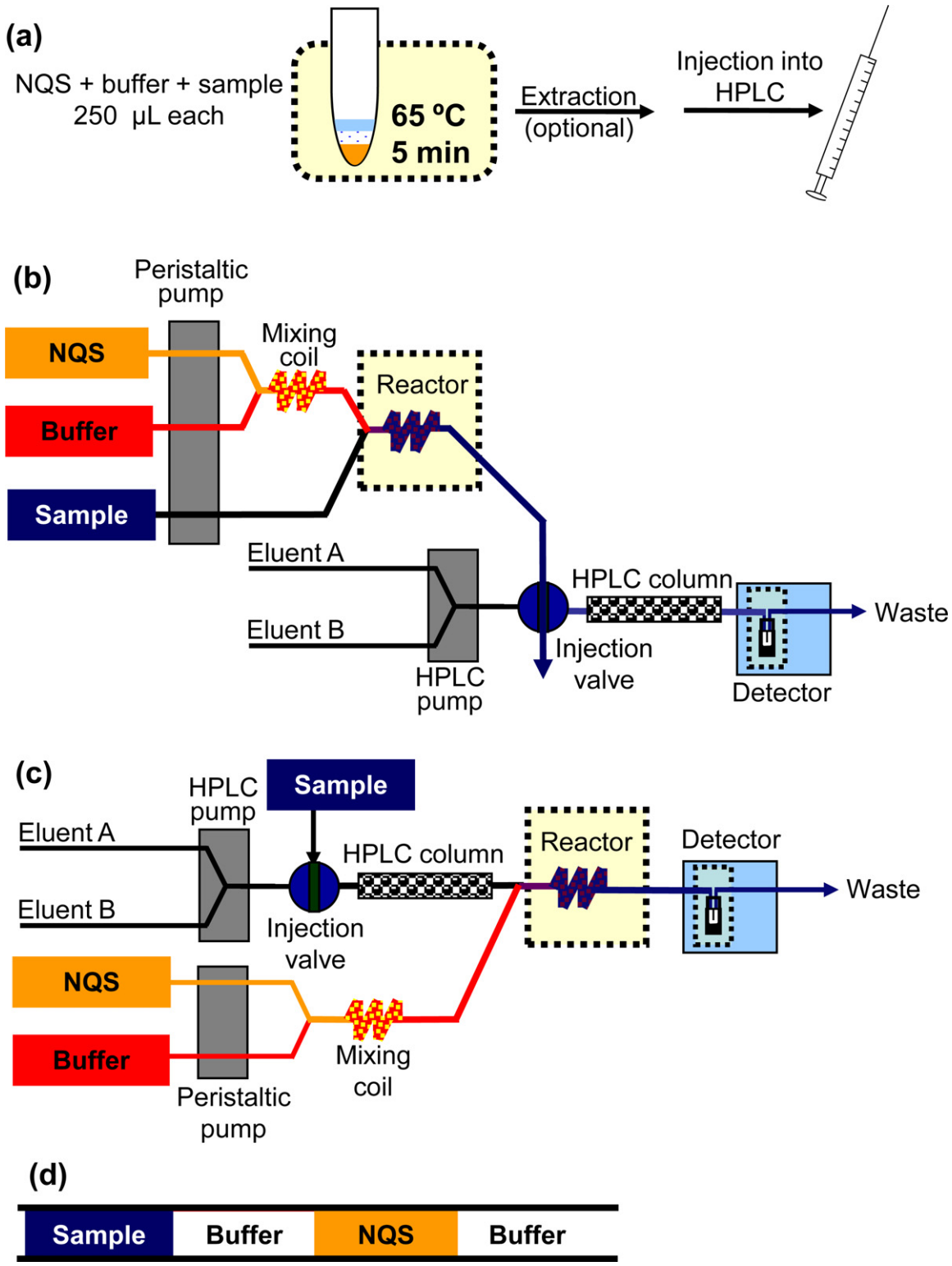

Fig. 3. Approaches for the derivatization of amines with 1,2,-naphthoquinone-4-sulfonate. (a) Offline pre-column HPLC; (b) online pre-column HPLC; (c) post-column HPLC and (d) in-capillary (mixing tandem mode) CE.

online pre-column derivatization of histamine is affected by the wine matrix. In the off-line pre-column procedure, although some amines are rather robust in front of the matrix variations, tyramine and ethanolamine displayed significant sensitivity variations. In the post-column method, matrix effects are not noticeable. The standard addition method has been adopted to carry out the calibration in the cases of changes in the sensitivity. Besides, wine matrix components, side reaction products and reagent excess were present in the reaction mixture in pre-column labeling. These compounds may act as interferences, especially in the case of UV detection, so they should be removed conveniently. In Ref. [76], a liquid–liquid extraction procedure with CH_2Cl_2 as an organic solvent has been applied to recover derivatives efficiently while most of interfering species remain in the aqueous phase. In the HPLC–MS method,

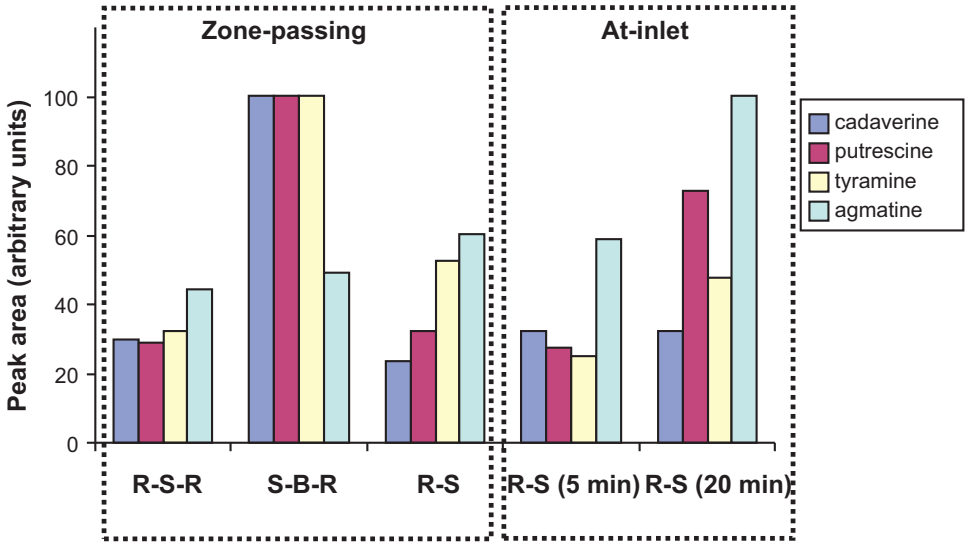

Fig. 4. Optimization of strategies of in-capillary derivatization of amines with 1,2,-naphthoquinone-4-sulfonate. R, reagent; S, sample; B, buffer.

however, the extraction step is not required since amines in co-eluting peaks can be resolved satisfactorily by recording selected ions characteristic of each analyte [87].

Regarding CE methods, Garcia-Villar et al. have combined field-amplified sample stacking and in-capillary derivatization with NQS for the determination of histamine, tryptamine, phenylethylamine, tyramine, ethanolamine, agmatine, serotonin, putrescine and cadaverine in wines [90]. Fig. 4 shows a comparison of the results obtained by zone-passing and at-inlet modes for various BAs chosen as a model. The throughout mode provided poor sensitivity due to the instability of the NQS in the running buffer (results not shown in the figure). With the exception of agmatine derivative, the at-inlet strategy did not improve the sensitivity with respect to the zone-passing results. Note that the kinetic development of the derivatization was already accomplished under dynamic conditions of the CE run for almost all amines. Best general results were obtained using zone-passing with the mixed tandem mode (R–B–S) so that this strategy was finally selected to perform the in-capillary derivatization of the biogenic amines with the NQS.

The comparison of figures of merit of the reported methods indicates that the best detection limits (LODs) are achieved with precolumn HPLC–MS, with a value of 0.03 mg L^{-1} for histamine. For online and offline precolumn HPLC-UV, LODs for histamine are 0.16 and 0.22 mg L^{-1}, respectively. The great performance of the electrophoretic preconcentration by stacking is evidenced by an excellent LOD of 0.37 mg L^{-1} for histamine. The poorer values are obtained for the post-column approach due to the higher level of noise and the dilution of analytes into the derivatization system. Similarly, limits of quantification (LOQs) are better in the HPLC–MS method, with values in the range 0.76 mg L^{-1}–13.5 mg L^{-1}, depending on the amine. Regarding accuracy, the quantitative performance of the CE-UV method is satisfactory, with recoveries from 89 to 96%. For the online precolumn HPLC-UV method, recovery values of 100.5–110.0% are obtained using the standard addition method for building the calibration models. Best results are provided by the offline precolumn HPLC-UV and HPLC–MS methods with recoveries in the range 94.6–103.5% and 93.4–103.2%, respectively.

4. Conclusions

There are a wide variety of reagents that have been utilized for the determination of BAs in wines. Sulfonyl chlorides, chloroformates, acyl chlorides, etc. require quite drastic experimental conditions to reach the completeness of the reaction so they have been exploited in pre-column approaches. Other reagents such as OPA and NQS are more versatile due to their fast and mild reaction conditions so that they can also be applied to post-column and on-column methods. Sample treatments may rely on adsorption processes for removing interferences from polyphenols and other substances. Besides, the extraction of derivatives prior to chromatographic analysis has been pointed out as an excellent option to separate the analytes from matrix components and reagent excess. These steps may contribute to improve the performance of the corresponding chromatographic or electrophoretic methods. Regarding sensitivity and limits of detections, even CE methods are suitable for quantifying the most relevant amines such as histamine, tyramine, putrescine and cadaverine. Although improvements for increasing the robustness of the CE methods are still required, the combination of electrophoretic preconcentration based on stacking with in-capillary derivatization is recognized as a highly attractive option for straightforward analysis of BAs in wines.

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References

[1] M.H. Silla-Santos, Int. J. Food Microbiol. 29 (1996) 213.
[2] R.E. Anli, M. Bayram, Food Rev. Int. 25 (2009) 86.
[3] A. Halász, Á. Baráth, L. Simon-Sarkadi, W. Holzapfel, Trends Food Sci. Technol. 5 (1994) 42.
[4] A.Y. Smit, W.J. du Toit, M. du Toit, S. Afr. J. Enol. Vitic. 29 (2008) 109.
[5] C. Jansen, M. van Dusseldorp, K.C. Bottema, A.E.J. Dubois, Ann. Allergy Asthma Immunol. 91 (2003) 233.
[6] R.C. Peatfield, G. Fletcher, K. Rhodes, I.M. Gardiner, J. de Belleroche, J. Headache Pain 4 (2003) 18.
[7] E. Diel, N. Bayas, A. Stibbe, S. Müller, A. Bott, D. Schrimpf, F. Diel, Inflamm. Res. 46 (1997) 87.
[8] C. Ancin-Azpilicueta, A. González-Marco, N. Jiménez-Moreno, Crit. Rev. Food Sci. Nutr. 48 (2008) 257.
[9] J.A. Pérez-Serradilla, M.D. Luque de Castro, Food Chem. 111 (2008) 447.
[10] A.P. Marques, M.C. Leitao, M.V.S. Romao, Food Chem. 107 (2008) 853.
[11] F. Cecchini, M. Morassut, Food Chem. 123 (2010) 263.
[12] L. Manfroi, P.H.A. Silva, L.A. Rizzon, P.S. Sabaini, M.B.A. Gloria, Food Chem. 116 (2009) 208.
[13] I. Rosi, F. Nannelli, G. Giovani, LWT Food Sci. Technol. 42 (2009) 525.
[14] V. Del Prete, A. Costantini, F. Cecchini, M. Morassut, E. García-Moruno, Food Chem. 112 (2009) 474.

[15] P. Hernández-Orte, A.C. Lapena, A. Pena-Gallego, J. Astrain, C. Baron, I. Pardo, L. Polo, S. Ferrer, J. Cacho, V. Ferreira, Food Res. Int. 41 (2008) 697.
[16] P.M. Izquierdo Canas, E. García Romero, S. Gómez Alonso, M. Fernández González, M.L.L. Palop Herreros, J. Food Comp. Anal. 21 (2008) 731.
[17] M.C. Vidal-Carou, A. Ambatlle-Espunyes, M.C. Ulla-Ulla, A. Mariné-Font, Am. J. Enol. Vitic. 41 (1990) 160.
[18] G.L. La Torre, R. Rando, M. Saitta, M. Alfa, R. Maisano, G. Dugo, It. J. Food Sci. 22 (2010) 28.
[19] L. Zhijun, W. Yongning, Z. Gong, Z. Yunfeng, X. Changhu, Food Chem. 105 (2007) 1530.
[20] J. Kiss, M. Korbasz, A. Sass-Kiss, J. Agric. Food Chem. 54 (2006) 8909.
[21] A. Sass-Kiss, G. Hajos, Acta Aliment. 34 (2005) 227.
[22] S.C. Souza, K.H. Theodoro, R.E. Souza, S. da Motta S, M. Beatriz, A. Gloria, Braz. Arch. Biol. Technol. 48 (2005) 53.
[23] R.E. Anli, N. Vural, S. Yilmaz, Y.H. Vural, J. Food Comp. Anal. 17 (2004) 53.
[24] K. Heberger, E. Csomos, L. Simon-Sarkadi, J. Agric. Food Chem. 51 (2003) 8055.
[25] I.M.P.L.V.O. Ferreira, O. Pinho, J. Food Prot. 69 (2006) 2293.
[26] M. Friedman, J. Agric. Food Chem. 52 (2004) 385.
[27] A. Onal, Food Chem. 103 (2007) 1475.
[28] P. Lehtonen, Am. J. Enol. Vitic. 47 (1996) 127.
[29] M. Herrero, V. Garcia-Canas, C. Simo, A. Cifuentes, Electrophoresis 31 (2010) 205.
[30] V. García-Canas, Cifuentes, Electrophoresis 29 (2008) 294.
[31] L. Simon-Sarkadi, E. Gelencser, A. Vida, Acta Aliment. 32 (2003) 89.
[32] I.A. Bulushi, S. Poole S, H. Deeth, G. Dykes, Crit. Rev. Food Sci. Nutr. 49 (2009) 369.
[33] S. Moret, L.S. Conte, J. Chromatogr. A 729 (1996) 363.
[34] S. Moret, D. Smela, T. Populin, L.S. Conte, Food Chem. 89 (2005) 355.
[35] M. Saaid, B. Saad, N.H. Hashim, A.S.M. Ali, M.I. Saleh, Food Chem. 113 (2009) 1356.
[36] N. Innocente, A. Biasutti, A. Padovese, S. Moret, Food Chem. 101 (2007) 1285.
[37] E. Dadakova, M. Krizek, T. Pelikanova, Food Chem. 116 (2009) 365.
[38] E. Mazzucco, F. Gosetti, M. Bobba M, E. Marengo, E. Robotti, M.C. Gennaro, J. Agric. Food Chem. 58 (2010) 127.
[39] M. Saaid, B. Saad, A.S.M. Ali, M.I. Saleh, C. Basheer, H.K. Lee, J. Chromatogr. A 1216 (2009) 5165.
[40] V. Pereira, M. Pontes, J.S. Camara, J.C. Marques, J. Chromatogr. A 1189 (2008) 435.
[41] K.J. Huang, C.Y. Wei, W.L. Liu, W.Z. Xie, J.F. Zhang, W. Wang, J. Chromatogr. A 1216 (2009) 6636.
[42] T.C. Chiu, Y.W. Lin, Y.F. Huang, H.T. Chang, Electrophoresis 27 (2006) 4792.
[43] W.J.M. Underberg, J.C.M. Waterval, Electrophoresis 23 (2002) 3922.
[44] R.M. Latorre, J. Saurina, S. Hernandez-Cassou, Electrophoresis 22 (2001) 4355.
[45] R.M. Latorre, S. Hernandez-Cassou, J. Saurina, J. Chromatogr. A 934 (2001) 105.
[46] S. Sentellas, J. Saurina, J. Sep. Sci. 26 (2003) 875.
[47] G.C. Derringer, D. Suich, J. Qual. Technol. 12 (1980) 214.
[48] G.J. Soleas, M. Carey, D.M. Goldberg, Food Chem. 64 (1999) 49.
[49] A. Marcobal, M.C. Polo, P.J. Martin-Álvarez, M.V. Moreno-Arribas, Food Res. Int. 38 (2005) 387.
[50] D. Kutlan, I. Molnar-Perl, J. Chromatogr. A 987 (2003) 311.
[51] T. Hyötyläinen, N. Savola, P. Lehtonen, M.L. Riekkola, Analyst 126 (2001) 2124.
[52] A. Sass-Kiss, E. Szerdahelyi, G. Hajds, Chromatographia 51 (2000) S316.
[53] M.C. Vidal-Carou, F. Lahoz-Portolés, S. Bover-Cid, A. Mariné-Font, J. Chromatogr. A 998 (2003) 235.
[54] J. Kiss, A. Sass-Kiss, J. Agric. Food Chem. 53 (2005) 10042.
[55] M.L. Latorre-Moratalla, J. Bosch-Fusté, T. Lavizzari, S. Bover-Cid, M.T. Veciana-Nogués, M.C. Vidal-Carou, J. Chromatogr. A 1216 (2009) 7715.
[56] O. Busto, M. Miracle, J. Guasch, F. Borrull, J. Chromatogr. A 757 (1997) 311.
[57] C. Proestos, P. Loukatos, M. Komaitis, Food Chem. 106 (2008) 1218.
[58] J. Hernández-Borges, G. D'Orazio, Z. Aturki, S. Fanali, J. Chromatogr. A 1147 (2007) 192.
[59] E.H. Soufleros, E. Bouloumpasi, A. Zotou, Z. Loukou, Food Chem. 101 (2007) 704.
[60] A. Zotou, Z. Loukou, E. Soufleros, I. Stratis, Chromatographia 58 (2003) 579.
[61] Z. Loukou, A. Zotou, Chromatographia 57 (2003) 429.
[62] G. Dugo, F. Vilasi, G.L. la Torre, T.M. Pellicano, Food Chem. 95 (2006) 672.
[63] Z. Loukou, A. Zotou, J. Chromatogr. A 996 (2003) 103.
[64] R. Romero, J.A. Jonsson, D. Gázquez, M.G. Bagur, M. Sánchez-Viñas, J. Sep. Sci. 25 (2002) 584.
[65] R. Romero, M. Sánchez-Viñas, D. Gázquez, M.G. Bagur, J. Agric. Food Chem. 50 (2002) 4713.
[66] R. Romero, D. Gazquez, M.G. Bagur, M. Sanchez-Viñas, J. Chromatogr. A 871 (2000) 75.
[67] T. Bauza, M.T. Kelly, A. Blaise, Food Chem. 105 (2007) 405.
[68] T. Bauza, A. Blake, F. Daumas, J.C. Cabanis, J. Chromatogr. A 707 (1995) 373.
[69] V. Lozanov, S. Petrov, V. Mitev, J. Chromatogr. A 1025 (2004) 201.
[70] P. Herbert, M.J. Cabrita, N. Ratola, O. Laureano, A. Alves, J. Environ. Sci. Health Part B 41 (2006) 1171.
[71] P. Herbert, M.J. Cabrita, N. Ratola, O. Laureano, A. Alves, J. Food Eng. 66 (2005) 315.
[72] P. Herbert, L. Santos, A. Alves, J. Food Sci. 66 (2001) 1319.
[73] S. Gómez-Alonso, I. Hermosín-Gutiérrez, E. García-Romero, J. Agric. Food Chem. 55 (2007) 608.
[74] J. Kirschbaum, I. Busch, H. Brückner, Chromatographia 45 (1997) 263.
[75] L.W. Cao, H. Wang, J.S. Li, H.S. Zhang, J. Chromatogr. A 1063 (2005) 143.
[76] J.S. Li, H. Wang, K.J. Huang, H.S. Zhang, Anal. Chim. Acta 575 (2006) 255.
[77] O. Ozdestan, A. Uren, Talanta 78 (2009) 1321.
[78] E.K. Paleologos, M.G. Kontominas, Anal. Chem. 76 (2004) 1289.
[79] A. Peña-Gallego, P. Hernández-Orte, J. Cacho, V. Ferreira, J. Chromatogr. A 1216 (2009) 3398.
[80] P. Hernández-Orte, A. Pena-Gallego, M.J. Ibarz, J. Cacho, V. Ferreira, J. Chromatogr. A 1129 (2006) 160.
[81] A. González-Marco, C. Ancin-Azpilicueta, J. Food Sci. 71 (2006) C544.
[82] O. Busto, M. Miracle, J. Guasch, F. Borrull, J. Liq. Chromatogr. Relat. Technol. 20 (1997) 743.
[83] N. Zhang, Y.Z. Zhao, H.S. Zhang, H. Wang, J. Sep. Sci. 31 (2008) 38.
[84] J. Kirschbaum, A. Meier, H. Bruckner, Chromatographia 49 (1999) 117.
[85] N. Garcia-Villar, J. Saurina, S. Hernández-Cassou, Anal. Chim. Acta 575 (2006) 97.
[86] N. Garcia-Villar, S. Hernández-Cassou, J. Saurina, J. Agric. Food Chem. 55 (2007) 7453.
[87] N. Garcia-Villar, S. Hernández-Cassou, J. Saurina, J. Chromatogr. A 1216 (2009) 6387.
[88] N. Garcia-Villar, J. Saurina, S. Hernández-Cassou, Analyst 130 (2005) 1286.
[89] L. Hlabangana, S. Hernández-Cassou, J. Saurina, J. Chromatogr. A 1130 (2006) 130.
[90] N. Garcia-Villar, J. Saurina, S. Hernández-Cassou, Electrophoresis 27 (2006) 474.
[91] K.B. Male, J.H.T. Luong, J. Chromatogr. A 926 (2001) 309.
[92] G. Nouadje, N. Simeon, F. Dedieu, M. Nertz, P. Pulg, F. Couderc, J. Chromatogr. A 765 (1997) 337.
[93] A. Kovacs, L. Simon-Sarkadi, K. Ganzler, J. Chromatogr. A 836 (1999) 305.
[94] N. Zhang, H. Wang, Z.X. Zhang, Y.H. Deng, H.S. Zhang, Talanta 76 (2008) 791.
[95] C.N. Jayarajah, A.M. Skelley, A.D. Fortner, R.A. Mathies, Anal. Chem. 79 (2007) 8162.
[96] M.J. Paik, Y. Choi, K.R. Kim, Anal. Chim. Acta 560 (2006) 218.
[97] J.O. Fernandes, M.A. Ferreira, J. Chromatogr. A 886 (2000) 183.
[98] K.K. Ngim, S.E. Ebeler, M.E. Lew, D.G. Crosby, J.W. Wong, J. Agric. Food Chem. 48 (2000) 3311.
[99] J. Saurina, S. Hernández-Cassou, R. Tauler, Anal. Chem. 67 (1995) 3722.
[100] J. Saurina, S. Hernández-Cassou, J. Chromatrogr. A 676 (1994) 311.
[101] J. Saurina, S. Hernández-Cassou, J. Chromatrogr. A 740 (1996) 21.