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Simultaneous determination of 3-monochloropropane-1,2-diol and acrylamide in food by gas chromatography-triple quadrupole mass spectrometry with coupled column separation

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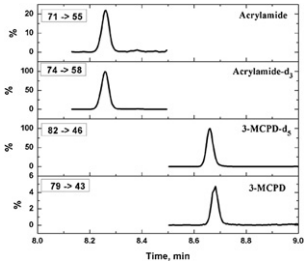
HIGHLIGHTS

- 3-MCPD and acrylamide were simultaneously detected by GC–MS/MS.
- A coupled column was applied to get sharp and symmetrical peaks.
- MS/MS in MRM was used to suppress matrix interferences and obtain high sensitivity.
- The method was successfully applied to different sample matrices.

GRAPHICAL ABSTRACT

MRM chromatograms of 3-MCPD and acrylamide in an instant noodle flavoring sample separated by coupled column.



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ABSTRACT

Both 3-monochloropropane-1,2-diol (3-MCPD) and acrylamide are contaminants found in heat-processed foods and their related products. A quantitative method was developed for the simultaneous determination of both contaminants in food by gas chromatography-triple quadrupole mass spectrometry (GC–MS/MS). The analytes were purified and extracted by the matrix solid-phase dispersion extraction (MSPDE) technique with Extrelut NT. A coupled column (a 3 m Innowax combined with a 30 m DB-5 ms) was developed to separate both compounds efficiently without derivatization. Triple quadrupole mass spectrometry in multiple reaction monitoring mode (MRM) was applied to suppress matrix interference and obtain good sensitivity in the determination of both analytes. The limit of detection (LOD) in the sample matrix was 5 μg kg^{-1} for 3-MCPD or acrylamide. The average recoveries for 3-MCPD and acrylamide in different food matrices were 90.5–107% and 81.9–95.7%, respectively, with the intraday relative standard deviations (RSDs) of 5.6–13.5% and 5.3–13.4%, respectively. The interday RSDs were 6.1–12.6% for 3-MCPD and were 5.0–12.8% for acrylamide. Both contaminants were found in samples of bread, fried chips, fried instant noodles, soy sauce, and instant noodle flavoring. Neither 3-MCPD nor acrylamide was detected in the samples of dairy products (solid or liquid samples) and non-fried instant noodles.

1. Introduction

3-Monochloropropane-1,2-diol (3-MCPD) is a by-product of an acid-hydrolyzed vegetable protein (acid-HVP, an ingredient for flavoring) [1]. High levels of 3-MCPD were reportedly found in

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acid-HVP and its related products including soy sauce [2,3]. Different levels of 3-MCPD were also found in various heat-processed foods [3,4]. Acrylamide is produced when carbohydrate-rich foods are exposed to high temperatures [5]. Previous studies found high acrylamide concentrations in fried or baked chips [6–10]. Both 3-MCPD and acrylamide exist in heat-processed foods [4]. The presence of both contaminants in fried carbohydrates or instant noodle flavoring (a popular fast food in Asian countries) should be monitored more precisely. 3-MCPD is harmful to both male fertility and kidney functions when given regularly in high doses [3,11]. Acrylamide is a well known neurotoxin compound [12] and a potential carcinogen in humans [13]. The maximum level (ML) of 3-MCPD set by the European Union is 20 $\mu g\,kg^{-1}$ in soy sauce or HVP [14]. Although no ML was set for acrylamide, the exposure of humans to acrylamide should be kept as low as possible because of carcinogenic effects [15].

A simultaneous determination method will help study and control the presence of both contaminants in related foods. Liquid chromatography-triple quadrupole mass spectrometry (LC–MS/MS) is preferable for measuring acrylamide [16–24] but not for analyzing trace 3-MCPD levels in complex matrices [4,25]. Gas chromatography–mass spectrometry (GC–MS) demonstrates poor peak shape, low sensitivity, and high susceptibility to matrix interferences. Hence, GC–MS is not suitable for detecting low molecular weight compounds with high polarity such as 3-MCPD and acrylamide. Derivatization techniques can be used to obtain characteristic ions with high molecular weight and decrease the polarity of both compounds [3,4,25]. Heptafluorobutyrylimidazole (HFBI) [26–30], phenylboronic acid [31,32], acetone [33,34], or N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA) as a silylation reagent [35] was used to react with the hydroxyl group in 3-MCPD. Bromination was applied to modify the double bond in acrylamide and improve column efficiency [36–38]. Different chemical reactions were used because of the different functional groups in 3-MCPD and acrylamide. Finding a derivatization reagent for the simultaneous determination of both analytes is difficult. Previous studies used GC and GC/MS for the direct determination of 3-MCPD [3,25,39] or acrylamide [40–43]. However, the limit of detection (LOD, 100 $\mu g\,kg^{-1}$) was unsatisfactory with respect to the regulation of EU ML (20 $\mu g\,kg^{-1}$) for 3-MCPD. Meanwhile, a 30 m polyethylene glycol column was used in the previous studies and the high column bleed was not suitable for GC–MS or gas chromatography–triple quadrupole mass spectrometry (GC–MS/MS). A coupled column was introduced to improve peak tailing and directly separate both analytes in this study. Triple quadrupole mass spectrometry was used to suppress matrix interferences and obtain sufficient sensitivity.

2. Experimental

2.1. Chemicals and reagents

Neat 3-MCPD and acrylamide-d_3 (100 $\mu g\,mL^{-1}$ in methanol) were purchased from Sigma–Aldrich (St. Louis, MO, USA) and CIL, Inc. (Andover, MA, USA), respectively. Acrylamide and 3-MCPD-d_5 were provided by Dr. Ehrenstorfer (Augsburg, Germany). All standards were 99.0% minimum purity. Hexane, ethyl acetate, methanol, and diethyl ether (HPLC grade) were purchased from TEDIA (Fairfield, OH, USA). Extrelut™ NT was obtained from Merck (Darmstadt, Germany). Ultra-pure water was prepared from a Millipore system (Bedford, MA, USA). Sodium sulphate (Na_2SO_4) and sodium chloride (NaCl) were bought from Huadong Medicine (Hangzhou, China) and dried at 500 °C for 4 h before use.

2.2. Preparation of standards

Single standard solutions of 3-MCPD, 3-MCPD-d_5, and acrylamide were prepared in methanol at a concentration of 1 $mg\,mL^{-1}$ each. 3-MCPD-d_5 and acrylamide-d_3 were used as internal standards for 3-MCPD and acrylamide, respectively.

The concentration was 10 $\mu g\,mL^{-1}$ for the standard mixture solution and 20 $\mu g\,mL^{-1}$ for the spiking internal standard mixture in methanol. A seven-point (10, 20, 50, 100, 200, 500, and 1000 $ng\,mL^{-1}$) calibration curve of the standard mixture was prepared by diluting the standard mixture in ethyl acetate, with the concentration of the internal standard at 0.4 $\mu g\,mL^{-1}$ for each point.

2.3. Instrumentation

An Agilent 7890A GC and 7000B triple quadrupole MSD with electron impact ionization mode was used in this study. 3-MCPD and acrylamide were simultaneously separated by a coupled column: a 3 m Innowax (0.32 mm i.d., 0.25 μm df, J&W, cross-bonded polyethylene glycol) combined in sequence with a 30 m DB-5 ms (0.25 mm i.d., 0.25 μm df, J&W, (5%-phenyl)-methylpolysiloxane) by a quartz capillary column connector (Agilent, USA). The inlet and transfer line temperatures were 250 and 260 °C, respectively. The oven temperature started at 50 °C for 3 min, increased to 250 °C at a rate of 30 °C min^{-1}, and finally held at 250 °C for 5 min. The ion source and quadrupole temperatures were 300 and 150 °C, respectively. Nitrogen was used as the collision gas at a flow rate of 1.5 mL min^{-1}. Helium was used as the carrier gas for GC and as the quench gas for MS/MS at a flow rate of 1.0 and 2.25 mL min^{-1}, respectively. The injection volume was 1 μL using splitless mode for GC, and the solvent delay was 5 min for MSD. The mass ranges for full and daughter scans were m/z 40 amu–350 amu and 20 amu–100 amu, respectively. MS/MS transitions were optimized by daughter scan (Table 1).

2.4. Sample preparation

2.4.1. Liquid samples such as soy sauce or liquid milk

Approximately 1 g of a homogenized sample was weighed into a 15 mL beaker, spiked with 20 μL of the internal standard solution (20 $\mu g\,mL^{-1}$), and then thoroughly mixed. Subsequently, the sample was mixed with a 1 g aliquot of Extrelut™ NT. After incubating for 15 min at room temperature, the mixture was transferred to a glass chromatographic column (1.0 cm i.d., 20 cm length) containing a 0.5 cm layer of anhydrous Na_2SO_4 and a 0.5 g aliquot of Extrelut™ NT. The column was gently shaken to compact the contents. Then, another 0.5 cm layer of anhydrous Na_2SO_4 was added to the column. The prepared column was washed with 10 mL of 70% hexane/diethyl ether mixture (v/v) at a flow rate of 1 mL min^{-1}. Thereafter, 12 mL of 50% diethyl ether/ethyl acetate mixture (v/v) was used to elute 3-MCPD and acrylamide. The eluent was evaporated to approximately 1 mL under a gentle stream of nitrogen at 35 °C. About 100 mg of Na_2SO_4 was used for dehydration. The mixture was then centrifuged for 5 min at 3000 rpm, and the clear solution was measured by GC–MS/MS.

2.4.2. Solid samples such as powdered milk or semi-solid flavoring from instant noodles

Approximately 0.5 g of a homogenized sample was weighed into a 15 mL beaker and then spiked with 10 μL of the internal standard solution (20 $\mu g\,mL^{-1}$) by a 10 μL microsyringe. The sample was thoroughly mixed with 1 mL of 10% NaCl in water and then mixed with a 1 g aliquot of Extrelut™ NT. The next steps were the same as those mentioned in Section 2.4.1. The extract was concentrated to approximately 0.5 mL before injection.

Table 1
MS/MS parameters for 3-MCPD and acrylamide.

Name	Precursor ion (*m*/*z*)[a]	Transition ion (*m*/*z*)	Dwell time (ms)	Collision energy (V)
3-MCPD-d_5	82	46	40	8
	84	46	40	8
3-MCPD	79	43	40	8
	81	43	40	8
Acrylamide-d_3	74	58	40	5
	74	30	40	18
Acrylamide	71	55	40	5
	71	27	40	18

[a] The first transition was used for quantitative method.

2.4.3. Solid samples with high content of starch-based foods such as fried chips, instant noodles, or bread

Approximately 0.5 g of a homogenized sample was weighed into a 25 mL beaker and then spiked with 10 μL of the internal standard solution (20 μg mL^{-1}). The sample was thoroughly mixed with 3 mL of 10% NaCl in water by gently stirring and then soaked for 15 min without agitation. The soaked sample was thoroughly mixed with a 3.5 g aliquot of Extrelut™ NT. After incubating for 15 min, the mixture was transferred to a glass chromatographic column (2.0 cm i.d., 50 cm length) containing a 1 cm layer of anhydrous Na_2SO_4 and a 1.5 g aliquot of Extrelut™ NT. The column was gently shaken to compact the contents. Thereafter, another 1 cm layer of anhydrous Na_2SO_4 was added to the column. The prepared column was washed with 40 mL of 70% hexane/diethyl ether mixture (v/v) at a flow rate about 3 mL min^{-1}. Subsequently, 50 mL of 50% diethyl ether/ethyl acetate mixture (v/v) was used to elute 3-MCPD and acrylamide. The eluent was concentrated to approximately 2 mL by rotary evaporation at 35 °C and then quantitatively transferred to a 5 mL test tube by washing twice with 1 mL of ethyl acetate. The extract was continuously evaporated to approximately 0.5 mL and then dehydrated with approximately 100 mg of Na_2SO_4. The resulting mixture was centrifuged for 5 min at 3000 rpm, and the remaining clear solution was measured by GC–MS/MS.

3. Results and discussion

3.1. Mass spectra of 3-MCPD and acrylamide

Full-scan mass spectra of 3-MCPD, acrylamide, and their deuterated isotope internal standards in single MS are shown in Fig. 1. The fragments of 3-MCPD in MS were described by R. Wittmann [39], whereas those of acrylamide were described by K. Hoenicke et al. [43]. The fragments of the corresponding characteristic ions in MS/MS are presented in Fig. 2. For single ion MS, the characteristic ions are too simple to be identified from the complex matrix at trace levels. Furthermore, two (*m*/*z* 71 and 55 for acrylamide) or three (*m*/*z* 79, 81, and 61 for 3-MCPD) characteristic ions would not satisfy the identification requirements for residue analysis (at least four ions for single mass) [44] if the most matrix-sensitive ions of *m*/*z* 44 and 43 are not considered. In this study, triple quadrupole mass spectrometry was applied to improve matrix interference and increase the sensitivity for 3-MCPD and acrylamide determination.

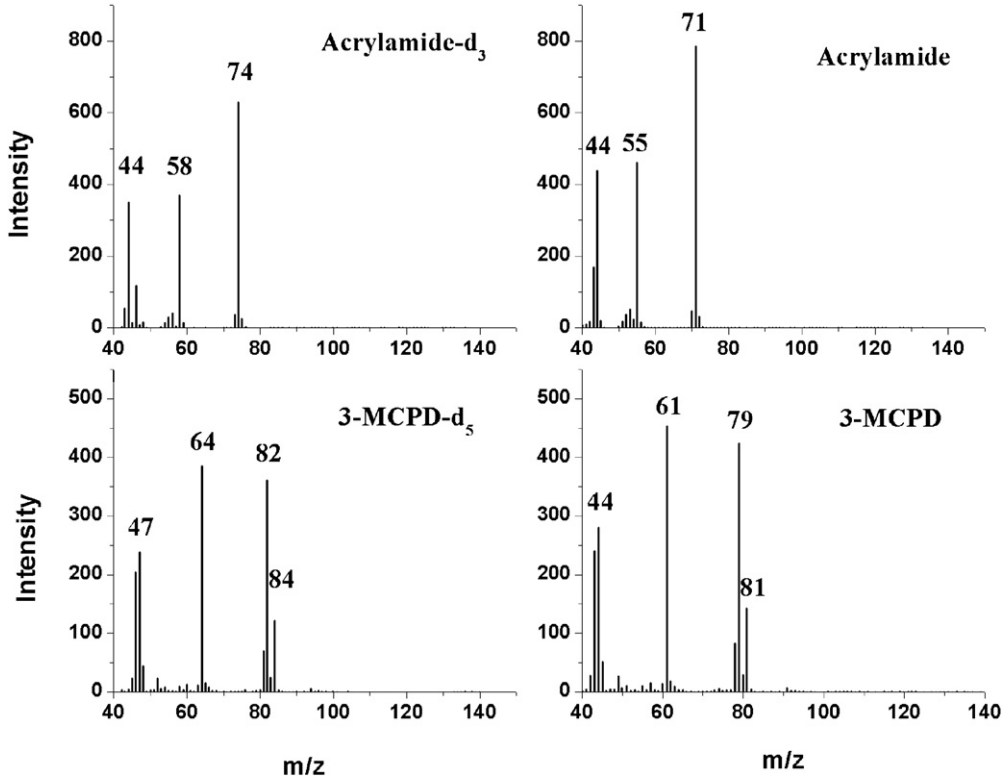

Fig. 1. Full-scan mass spectra of 3-MCPD, acrylamide, and their deuterated internal standards.

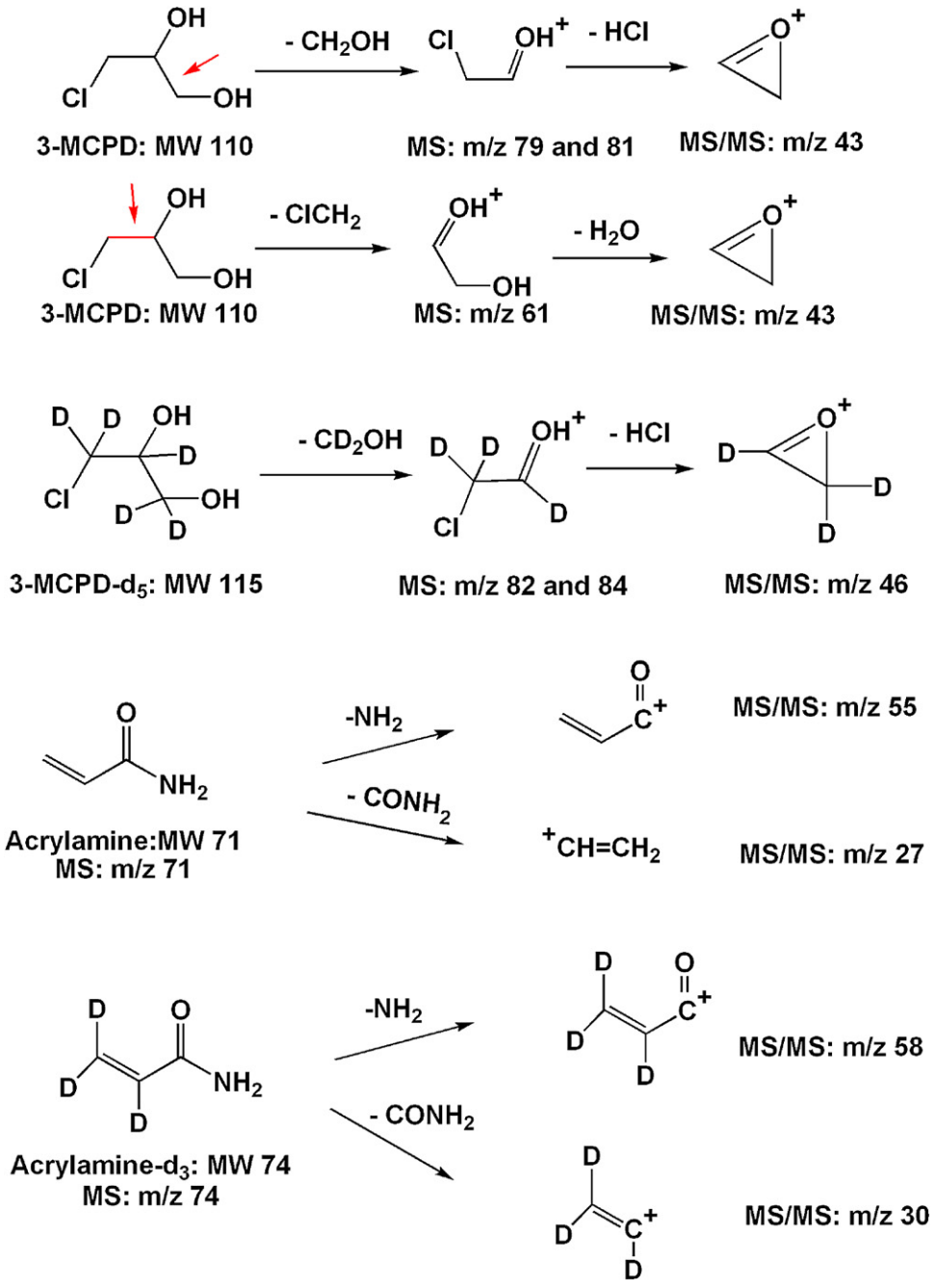

Fig. 2. Fragments of 3-MCPD, acrylamide, and their deuterated internal standards in single and triple quadrupole mass spectrometry (MW, molecular weight).

The transitions for the two analytes are presented in Table 1. Two transitions for each analyte can satisfy the identification requirements of MS/MS.

3.2. Simultaneous separation of 3-MCPD and acrylamide

Both analytes are compounds with high polarity and water solubility. Therefore, the key points for a simultaneous determination method are the selection of a highly efficient GC column and the cleanup steps for the separation of analytes from the matrix.

3.2.1. Separation of 3-MCPD and acrylamide by a coupled column

A column for GC–MS or GC–MS/MS requires low bleed and high efficiency. High column efficiency was found for acrylamide, whereas peak broadening and low sensitivity were noted for 3-MCPD when separated by a 30 m Innowax column with a stationary phase of polyethylene glycol. Furthermore, high bleed will result from this kind of column [45]. A column with weak polarity, such as DB-5 ms, is preferable for GC-MS. However, poor column efficiency (high peak tailing) will be observed for polar compounds such as 3-MCPD and acrylamide when separated by DB-5 ms. Although derivatization could decrease polarity and improve tailing, no chemical reagents could be found to react with both compounds because of the different functional groups in 3-MCPD and acrylamide.

A coupled column was developed to separate both analytes without derivatization. Only a short Innowax column (polyethylene glycol) was used in the coupled column system to decrease peak tailing and column bleed as low as possible. A 30 m DB-5 ms was used as the analytical column to maintain the selectivity of

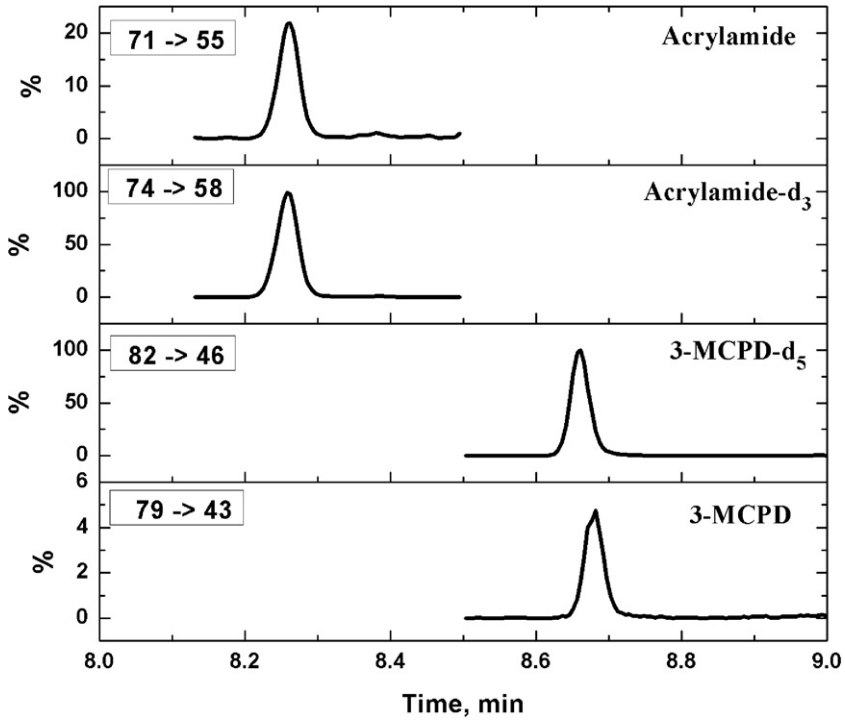

Fig. 3. MRM chromatograms of 3-MCPD and acrylamide separated by a coupled column in instant noodle flavoring with concentrations of 26 and 110 μg kg^{-1}, respectively.

the coupled column. The two parts were combined by a two-way quartz capillary column connector. Sharp and symmetrical peaks were found for both analytes after using the coupled column (Fig. 3).

The improvement in peak tailing for polar compounds depends on the short length of coupled polar column [45]. The length of the Innowax column was optimized according to the column efficiency parameter. That is, the number of theoretical plate (n). The value of n increased as the length of the Innowax column increased from 0 m to 3 m. The major column bleed came from the short polar part in the coupled column. Hence, a 3 m Innowax column is recommended from this study. The deviations in the retention time (t_R) for both analytes were below 0.2% within 200 sample injections. The short coupled Innowax column can also serve as a guard column for the next 30 m of DB-5 ms. The DB-5 ms column efficiency returns to original levels when a new 3 m Innowax is installed after hundreds of injections.

3.2.2. Separation of 3-MCPD and acrylamide from the matrix

As polar compounds, both analytes are easy to be purified from a lipid-soluble matrix but hard to be separated from water and water-soluble compounds. The matrix solid-phase dispersion extraction (MSPDE) technique modified from 3-MCPD analysis [46–49] was used in the present study. The particle material of Extrelut NT was used to adsorb the water and distribute the matrix in solid phase. The lipid-soluble matrix can be cleaned by a weak polar solvent mixture (70% hexane/diethyl ether (v/v)), and the analytes can be eluted by a strong polar solvent mixture (50% diethyl ether/ethyl acetate (v/v)). Extraction and purification can be finished by a single step of MSPDE. No additional solvent extraction or centrifugation operations were used during these steps. For samples with high content of starch-based foods such as fried chips, instant noodles, or bread, Extrelut NT material may be adhered together by water-soaked samples. Therefore, more Extrelut NT materials should be used to distribute the sticky matrix. An aliquot of 3.5 g Extrelut NT was enough to obtain good results. Triple quadrupole mass spectrometry produced clear chromatograms in the matrix for both analytes without derivatization (Fig. 3).

3.3. Method validation

The method was validated before its application to the sample analysis. The linear range was 10 ng mL^{-1}–1000 ng mL^{-1}, with the correlation coefficient (r) exceeding 0.999 for both analytes. According to the sample preparation process and the signal-to-noise ratio (3:1) of the lower sensitive transition in the level of 20 μg kg^{-1}, the LOD for each analyte was 5 μg kg^{-1}. Three spiking levels (20, 200, and 500 μg kg^{-1}) with six parallel measurements in different sample matrices were studied to examine the recovery and intraday precision of the method (Table 2). The interday precision was measured in five days with two repetitions each day. The average recoveries for 3-MCPD and acrylamide were 90.5–107% and 81.9–95.7%, respectively, with the intraday relative standard deviations (RSDs) of 5.6–13.5% and 5.3–13.4%, respectively. The interday RSDs were 6.1–12.6% for 3-MCPD and were 5.0–12.8% for acrylamide.

3.4. 3-MCPD and acrylamide in food

Neither 3-MCPD nor acrylamide was detected in the samples of dairy products (solid or liquid samples) and non-fried instant noodles. Both analytes were found in some samples of bread, fried chips, fried instant noodles, soy sauce, and instant noodle flavoring. However, different levels of the two contaminants were found in these foods. In the samples of heat-processed foods such as bread, fried or baked chips, and fried instant noodles, the levels of 3-MCPD were less than 40 μg kg^{-1}, whereas those of acrylamide were 12 μg kg^{-1} to 1562 μg kg^{-1}. Although the concentrations of 3-MCPD in most samples of soy sauce were less than 20 μg kg^{-1}, two samples had 3-MCPD concentrations of more than 1000 μg kg^{-1}. High acrylamide concentrations (142 μg kg^{-1}–1274 μg kg^{-1}) were found in some samples of soy sauce, whereas no acrylamide was detected in most samples of soy sauce. No acrylamide was detected in the acid-HVP samples. Acrylamide contamination in this kind of samples should be of prime concern in the future. The levels of 3-MCPD and acrylamide in the samples of instant noodle flavoring

Table 2
Recoveries and RSDs in different foods.

Sample	Content ($\mu g\,kg^{-1}$)[a,b]	Spiking level ($\mu g\,kg^{-1}$)	3-MCPD			Acrylamide		
			Recovery (%)	RSD[c] (%)		Recovery (%)	RSD[c] (%)	
				Intraday	Interday		Intraday	Interday
Soy sauce	13	20	106	10.5	10.8	86.0	8.9	8.5
	ND	200	96.9	7.9	7.4	92.2	6.0	6.2
		500	95.5	8.1	6.9	90.6	5.7	6.6
Fried chips	8	20	103	11.3	12.6	82.5	13.4	12.8
	327	200	93.4	8.0	8.7	91.4	9.2	9.0
		500	95.2	7.3	7.1	91.7	7.0	7.5
Powdered milk	ND	20	103	8.9	8.4	92.1	8.6	8.0
	ND	200	96.6	8.0	7.9	94.6	7.4	7.5
		500	95.0	8.4	7.2	90.7	5.3	6.2
Liquid milk	ND	20	104	7.9	8.4	89.6	7.7	7.3
	ND	200	94.9	6.4	7.7	91.3	7.0	6.8
		500	92.1	5.7	6.1	92.7	6.1	6.4
Fried instant noodle	ND	20	107	12.4	11.3	81.9	11.0	12.5
	206	200	92.6	9.4	8.9	87.7	8.1	9.0
		500	90.7	7.0	8.2	93.0	6.5	7.8
Non-fried instant noodle	ND	20	105	9.6	9.0	89.9	7.6	8.2
	ND	200	90.5	7.5	8.3	91.6	5.3	5.0
		500	91.7	5.6	6.6	95.7	6.0	5.5
Flavoring from instant noodle	34	20	107	10.0	11.2	84.8	10.4	10.0
	97	200	94.8	8.8	8.5	90.9	8.0	8.4
		500	95.3	6.7	7.3	90.4	6.6	6.3
Bread	ND	20	102	13.5	12.2	88.8	9.7	10.3
	65	200	93.6	9.4	8.6	94.7	7.0	7.9
		500	97.1	7.6	8.9	91.5	8.2	7.5

[a] The contents of 3-MCPD and acrylamide, respectively, before spiking.
[b] ND, not detected.
[c] $n = 6$ for intraday RSD and $n = 2$ each day in 5 days for interday RSD.

were $8.2\,\mu g\ kg^{-1}$–$148\,\mu g\,kg^{-1}$ and $6.7\,\mu g\ kg^{-1}$–$186\,\mu g\,kg^{-1}$, respectively. 3-MCPD contamination may be attributed to the use of acid-HVP as an ingredient for flavoring. Tateo et al. reports on the presence of acrylamide contamination in flavorings such as sauces [50]. Future studies should focus on determining the source of this contamination. The results were compared with those measured by GC–MS with HFBI derivatization for 3-MCPD [29] and by LC–MS/MS for acrylamide [16]. The deviations were less than 15%. In the present study, both results can be obtained using only a single determination process.

4. Conclusions

A 30 m Innowax was efficient in separating acrylamide but not 3-MCPD because of peak broadening. A 3 m Innowax in the coupled column was enough to improve the peak tailing of both analytes with less column bleed. The coupled column can be a good choice for GC–MS/MS to increase the separation efficiency of polar and low molecular weight compounds such as 3-MCPD and acrylamide. Moreover, MS/MS was effective in suppressing matrix interferences for low molecular weight analytes. Satisfactory results were obtained for 3-MCPD and acrylamide separated by the coupled column and measured by GC–MS/MS in different matrices without derivatization. The coexistence of both contaminants in food should be of prime concern.

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References

[1] J. Velisek, J. Davidek, J. Hajslova, V. Kubelka, G. Janicek, B. Mankova, Z. Lebensm, Unters. Forsch. 167 (1978) 241–244.
[2] P.D. Collier, D.D.O. Cromie, A.P. Davies, J. Am. Oil Chem. Soc. 68 (1991) 785–790.
[3] I. Baer, B. de la Calle, P. Taylor, Anal. Bioanal. Chem. 396 (2010) 443–456.
[4] T. Wenzl, D.W. Lachenmeier, V. Gokmen, Anal. Bioanal. Chem. 389 (2007) 119–137.
[5] Y. Zhang, Y.R. Ren, Chem. Rev. 109 (2009) 4375–4397.
[6] Swedish National Food Administration, Information about Acrylamide in Food, April 24, 2002, http://www.slv.se
[7] J. Keramat, A. LeBail, C. Prost, N. Soltanizadeh, Food Bioprocess Technol. 4 (2011) 340–363.
[8] T. Wenzl, E. Anklam, Food Addit. Contam. 24 (2007) 5–12.
[9] R.J. Foot, N.U. Haase, K. Grob, P. Gondé, Food Addit. Contam. 24 (2007) 37–46.
[10] J. Keramat, A. LeBail, C. Prost, M. Jafari, Food Bioprocess Technol. 4 (2011) 530–543.
[11] FAO/WHO, Discussion paper on acid HVP containing products and other products containing chloropropanols, in: Proc Session 38 of Codex Committee on Food Additives and Contaminants, The Hague, The Netherlands, April 24–28, 2006.
[12] P.M. LeQuesne, Specific environmental neurotoxins, in: P.S. Spencer, H.H. Schaumburg (Eds.), Experimental and Clinical Neurotoxicology, 1st ed., Williams & Wilkins, Baltimore, MD, 1980, p. 309.
[13] A. Besaratinia, G.P. Pfeifer, Carcinogenesis 28 (2007) 519–528.
[14] EC, Regulation No. 1881/2006, Setting maximum levels for certain contaminants in foodstuffs, Off. J. Eur. Union L364 (2006) 5–24.
[15] Scientific Committee on Toxicity Ecotoxicity and the Environment (CSTEE), Opinion on the Results of the Risk Assessment of acrylamide, Report Version: October 2000 Carried out in the Framework of Council Regulation (EEC) 793/93 on the Evaluation and Control of the Risks of Existing Substances 1, Opinion Expressed at the 22nd CSTEE Plenary Meeting, Brussels, March 6–7, 2001.
[16] U.S. Food and Drug Administration (FDA), Draft: Detection and Quantitation of Acrylamide in Foods, 2003 http://www.fda.gov/Food/FoodSafety/FoodContaminantsAdulteration/ChemicalContaminants/Acrylamide/ucm053537.htm
[17] Y. Zhang, Y. Ren, J. Jiao, D. Li, Anal. Chem. 83 (2011) 3297–3304.
[18] S.E.K. Tekkeli, C. Önal, A. Önal, Food Anal. Methods 5 (2012) 29–39.

[19] N.J. Nielsen, K. Granby, R.V. Hedegaard, L.H. Skibsted, Anal. Chim. Acta 557 (2006) 211–220.
[20] Y. Govaert, A. Arisseto, J. Van Loco, E. Scheers, S. Fraselle, E. Weverbergh, J.M. Degroodt, L. Goeyens, Anal. Chim. Acta 556 (2006) 275–280.
[21] L. Karasek, T. Wenzl, E. Anklam, Food Chem. 114 (2009) 1555–1558.
[22] J. Rosen, A. Nyman, K.E. Hellenas, J. Chromatogr. A 1172 (2007) 19–24.
[23] O. Kaplan, G. Kaya, C. Ozcan, M. Ince, M. Yaman, Microchem. J. 93 (2009) 173–179.
[24] T. Wenzl, L. Karasek, J. Rosen, K.E. Hellenaes, C. Crews, L. Castle, E. Anklam, J. Chromatogr. A 1132 (2006) 211–218.
[25] R.H. Stadler, T. Goldmann, Compr. Anal. Chem. (2010) 705–728 (Chapter 20).
[26] CEN, Foodstuffs: Determination of 3-Monochloropropane-1,2-diol by GC/MS (EN 14573), European Committee for Standardization, Brussels, 2004.
[27] N. Leon, V. Yusa, O. Pardo, A. Pastor, Talanta 75 (2008) 824–831.
[28] E. Berger-Preiß, S. Gerling, E. Apel, A. Lampen, O. Creutzenberg, Anal. Bioanal. Chem. 398 (2010) 313–318.
[29] X. Xu, Y. Ren, P. Wu, J. Han, X. Shen, Food Addit. Contam. 23 (2006) 110–119.
[30] S. Abu-El-Haj, M.J. Bogusz, Z. Ibrahim, H. Hassan, M. Al Tufail, Food Contr. 18 (2007) 81–90.
[31] P. Calta, J. Velisek, M. Dolezal, S. Hasnip, C. Crews, Z. Reblova, Eur. Food Res. Technol. 218 (2004) 501–506.
[32] C.M. Breitling-Utzmann, H. Hrenn, N.U. Haase, G.M. Unbehend, Food Addit. Contam. 22 (2005) 97–103.
[33] C. Retho, F. Blanchard, Food Addit. Contam. 22 (2005) 1189–1197.
[34] F.M. Dayrit, M.R. Ninonuevo, Food Addit. Contam. 21 (2004) 204–209.
[35] I. Racamonde, P. González, R.A. Lorenzo, A.M. Carro, J. Chromatogr. A 1218 (2011) 6878–6883.
[36] A. Pittet, A. Périsset, J.M. Oberson, J. Chromatogr. A 1035 (2004) 123–130.
[37] Y. Zhang, Y. Ren, H. Zhao, Anal. Chim. Acta 584 (2007) 322–332.
[38] Y. Zhu, G. Li, Y. Duan, S. Chen, C. Zhang, Y. Li, Food Chem. 109 (2008) 899–908.
[39] R. Wittmann, Z. Lebensm, Unters. Forsch. 193 (1991) 224–229.
[40] S.H. Kim, J.H. Hwang, K.G. Lee, Food Sci. Biotechnol. 20 (2011) 835–839.
[41] M.R. Lee, L.Y. Chang, J. Dou, Anal. Chim. Acta 582 (2007) 19–23.
[42] L. Dunovská, T. Čajka, J. Hajšlová, K. Holadová, Anal. Chim. Acta 578 (2006) 234–240.
[43] K. Hoenicke, R. Gatermann, W. Harder, L. Hartig, Anal. Chim. Acta 520 (2004) 207–215.
[44] European Union (EU), Commission Decision 2002/657/EC implementing Council Directive 96/23/EC concerning the performance of analytical methods and the interpretation of results, Off. J. L221 (2002) 8–36.
[45] X.M. Xu, G.L. Song, Y. Zhu, J. Zhang, Y.X. Zhao, H.T. Shen, Z.X. Cai, J.L. Han, Y.P. Ren, J. Chromatogr. B 876 (2008) 103–108.
[46] D.C. Meierhans, S. Bruehlmann, J. Meili, C. Taeschler, J. Chromatogr. A 802 (1998) 325–333.
[47] R. Macarthur, C. Crews, A. Davies, P. Brereton, P. Hough, D. Harvey, Food Addit. Contam. 17 (2000) 903–906.
[48] P.J. Nyman, G.W. Diachenko, G.A. Perfetti, Food Addit. Contam. 20 (2003) 903–908.
[49] C. Crews, P. Hough, P. Brereton, D. Harvey, R. Macarthur, W. Matthews, Food Addit. Contam. 19 (2002) 22–27.
[50] F. Tateo, M. Bononi, G. Andreoli, J. Food Compos. Anal. 20 (2007) 232–235.