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Isotope Dilution LC-MS/MS Method for Glycine Betaine in Manila Clam (*Tapes philippinarum*)

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Food Analytical Methods

Isotope dilution LC-MS/MS method for glycine betaine in Manila clam (*Tapes philippinarum*) --Manuscript Draft--

Manuscript Number:	
Full Title:	Isotope dilution LC-MS/MS method for glycine betaine in Manila clam (<i>Tapes philippinarum</i>)
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Keywords:	Glycine betaine; Manila clam; UHPLC-MS/MS; validation; endogenous compound; HILIC
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Abstract:	<p>Glycine betaine (GB) is a natural compound with demonstrated metabolic functions in mammals and beneficial effects on human body: it protects cells under osmotic stress, as organic osmolyte, and acts as methylating agent in several vital biochemical pathways.</p> <p>The main dietary sources of GB are vegetables, such as cereals, spinach, chard and beetroot, above all; shellfish is one of the richest animal sources. A simple method for the quantification of GB in the edible portion of Manila clams (<i>Tapes philippinarum</i>) was set up, using ultra performance liquid chromatography coupled to tandem mass spectrometry (UHPLC-MS/MS). Isotope-labelled internal standards were used during sample extraction, in order to ensure an accurate quantification.</p> <p>The method was successfully validated following the Commission Decision 657/2002/EC as guideline; since GB is an endogenous compound, present in very high concentrations in the target matrix, appropriate adjustments were taken. The method developed reported very satisfying performances in terms of linearity, trueness and precision; moreover its applicability was demonstrated on commercial pools of Manila clams.</p>

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5 **Isotope dilution LC-MS/MS method for glycine betaine in Manila clam (*Tapes philippinarum*)**

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27 **Abstract**

28 Glycine betaine (GB) is a natural compound with demonstrated metabolic functions in mammals and beneficial effects
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29 on human body: it protects cells under osmotic stress, as organic osmolyte, and acts as methylating agent in several vital
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30 biochemical pathways.
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31 The main dietary sources of GB are vegetables, such as cereals, spinach, chard and beetroot, above all; shellfish is one
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37 endogenous compound, present in very high concentrations in the target matrix, appropriate adjustments were taken.

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38 The method developed reported very satisfying performances in terms of linearity, trueness and precision; moreover its
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39 applicability was demonstrated on commercial pools of Manila clams.
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Keywords

42 Glycine betaine; Manila clam; UHPLC-MS/MS; validation; endogenous compound; HILIC

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Chemical compounds

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Glycine betaine (PubChem CID: 248); Betaine-(*trimethyl-D₉*) hydrochloride (PubChem CID: 16213877)

48 1. Introduction

49 Glycine betaine (GB) is a small natural compound, first isolated in the late nineteenth century from the juice of sugar
50 beets (*Beta vulgaris*), hence the name “betaine” (De Zwart et al. 2003). The chemical structure of this molecule derives
51 from the methylation of glycine, which forms a zwitterionic compound with a permanent cationic functional group (De
52 Zwart et al. 2003; Naresh Chary et al. 2012). This feature makes GB a highly polar but neutral compound, able to retain
53 its positive charge also at high pH (Lever and Slow 2010).

54 The GB intake could derive directly from the diet or from endogenous synthesis through the oxidation of choline by a
55 two-step enzymatic process (Lever and Slow 2010). GB can be naturally found in a variety of food: the richest animal
56 source is represented by shellfish (Zeisel et al. 2003), while the GB most abundant plants (De Zwart et al. 2003) (De
57 Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al.
58 al. 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al.
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60 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) (De Zwart et al. 2003) are grass family (particularly wheat) and other
61 belonging to the beet family, such as spinach, chard and beetroot (Lever and Slow 2010; Hefni et al. 2015) (Lever and
62 Slow 2010; Hefni et al. 2015).

63 Levels of GB introduced in the diet can also vary significantly according to the type of cooking methods: due to its high
64 water-solubility, huge losses in GB levels are expected to occur after boiling processes (De Zwart et al. 2003), while
65 baking treatments are not expected to lower the GB content of the meal, since the internal temperature (generally below
66 200°C) do not induce GB degradation (European Food Safety Agency 2005).

67 A recommended daily intake for GB has not been established yet; an average dietary intake has been calculated to be
68 between 100 and 300 mg/day. Higher plasma GB levels are found to be related to the intake of foods rich in nutrients as
69 complex carbohydrates and fibre (Ueland 2011); consumers can enhance significantly GB intake by increasing shellfish
70 consumption (De Zwart et al. 2003).

71 GB has two main physiologic roles in human health: it protects cells under osmotic stress, as organic osmolyte, and acts
72 as methylating agent in several vital biochemical pathways. GB permits to maintain optimal cell turgor without
73 affecting cellular functions, being highly compatible with enzymes and hormones activity. The enzyme “betaine
74 homocysteine methyl transferase” (BHMT) transfers a methyl group from GB to homocysteine and regulates GB
75 concentration controlling its partitioning for the use as an osmoprotectant or as a methyl donor (Ueland 2011). The
76 processes of methylation of homocysteine to methionine would contribute to nucleic acid, protein and lipid synthesis
77 and to the occurrence of several consequent beneficial effects (European Food Safety Agency 2005).

78 The methylation of homocysteine to methionine promotes the therapeutic role of GB in patients affected by
79 homocysteinemia and explains its important role in human health (Craig 2004). In 2011 the European Food Safety
80 Agency (EFSA) confirmed the scientific evidence of the beneficial effects of GB on cardiovascular system by
81 maintaining a physiologic homocysteine metabolism, achievable with the daily intake of at least 1.5 g of GB (European
82 Food Safety Agency 2011).

83 GB is also considered a lipotropic factor and contributes to the prevention or reduction of lipid accumulation in the
84 liver, especially due to ethanol-induced fatty infiltration (European Food Safety Agency 2005).

85 Moreover, methyl group availability influences metabolic activities correlated to gene transcription and genomic
86 stability (Ueland 2011). A diet rich in methylating agents (such as GB) has been reported to protect from colorectal
87 cancer (Bae et al. 2014) and to possibly reduce risk of breast cancer (Lever and Slow 2010). Methyl groups provided by
88 GB can also promote the synthesis of creatine, that contributes to enhance athletic performances in humans (Lever and
89 Slow 2010; Cholewa et al. 2014). At the end, GB plays also an important role in human development, from all stages of
90 gestation to early infancy; since choline catabolism to GB is irreversible, an adequate maternal intake of GB can ensure
91 choline supply for phospholipid and neurotransmitter synthesis to guarantee an optimal foetal and child
92 neurodevelopment (Lever and Slow 2010). It is increasingly well known that this compound plays an important role in
93 human health and is essential for normal body function; consequently, deficiency in its supply and metabolism would
94 lead to pathological consequences.

95 The small dimensions, the high polarity and the permanent cationic moieties of GB makes mass spectrometry (MS) an
96 attractive choice for its analysis (Airs and Archer 2010; Li et al. 2010; Naresh Chary et al. 2012). Most of the
97 publications available in literature reported methods for the detection and the quantification of GB in biological liquid
98 matrices (generally plasma, serum and urine); only few methods have been developed for food or other biological
99 matrices. To the best of our knowledge, only few studies reported data of GB in clams: de Zwart *et al.* (2003) used high
100 performance liquid chromatography (HPLC) coupled with UV detector for a large-scale monitoring on GB content in
101 foods; more recently, Ji *et al.* (2015) used *Tapes philippinarum* as bioindicator for metabolomics assays on
102 toxicological status of clams, using nuclear magnetic resonance spectroscopy. Li *et al.* (2010) developed and validated a
103 method using HPLC coupled with high resolution mass spectrometry for the analysis of GB in coral tissue; they
104 successfully tested the methods on clams, but any validation procedure on this matrix was lately published. The aim of
105 this work was to develop an ultra-performance liquid chromatography coupled with tandem mass spectrometry (UPLC-
106 MS/MS) method for the quantification of GB in *Tapes philippinarum*, in order to contribute to the assessment of the
107 health benefits of seafood consumption. The method proposed was validated considering the guidelines of the
108 Commission Decision 2002/657/EC (Commission Decision 2002), adequately adapted for the analysis of an

109 endogenous compound present in very high concentrations in matrix. Actually this is the first UPLC-MS/MS validated
110 method for the analysis of GB in Manila clam tissue.

111

112 **2. Material and methods**

113 **2.1 Reagents and chemicals**

114 Betaine BioUltra (purity $\geq 99.0\%$) and its deuterated analogue internal standard (IS), betaine-(*trimethyl-D₉*)
115 hydrochloride (D₉-BET) (purity $\geq 98.0\%$), were purchased by Sigma-Aldrich (St. Louis, MO, USA). Acetonitrile,
116 methanol, formic acid and ammonium acetate, all of LC-MS grade, were acquired by Sigma-Aldrich (St. Louis, MO,
117 USA); dichloromethane, of laboratory grade, from Merck (Darmstadt, Germany) and Ultrapure water was freshly
118 produced from a Milli-Q® water purification system (Merck, Darmstadt, Germany).

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120 **2.2 Sample preparation**

121 Samples of *Tapes philippinarum* were purchased in a local market in Bologna (Italy), suppressed by congelation and
122 stored at -18 °C. Before the extraction procedures, the tissues of 20 frozen Manila clams were minced and homogenised
123 in a glass tube with Ultraturrax (IKA, Staufen im Breisgau, Germany), to obtain a pool of samples. 50 mg of the pooled
124 clams, 10 mL of distilled water and 40 μ L of D₉-BET (100 μ g/g) were placed in a falcon tube and mixed with Vortex
125 mixer (Velp Scientifica, Monza, Italy) for about 1 minute. The sample was then centrifuged for 5 minutes at 8000 rpm
126 at 25°C and 5 mL of supernatant were transferred in a new falcon tube. The extract was purified vortexing with 3 mL of
127 dichloromethane for 1 minute. The complete separation in two phases was obtained by centrifugation, at the same
128 conditions described above; protein precipitation was then achieved adding 4 mL of acetonitrile LC-MS/MS to 1 mL of
129 the upper aqueous phase, mixing and centrifuging in the same conditions. Finally, 1 mL of supernatant was transferred
130 in a glass vial, ready for the injection in the UPLC-MS/MS.

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132 **2.3 UPLC-MS/MS analysis**

133 GB analysis were performed on a Waters Acquity UPLC® binary pump equipped with a Waters Acquity UPLC® BEH
134 HILIC (1.7 μ m 2.1 x 50 mm), fitted with a Waters VanGuard™ guard column with the same phase (5 x 2.1 mm, 1.7
135 μ m) (Waters Corporation, Milford MA, USA). The injection volume was 1 μ L and the column temperature was set to
136 40 °C. The analyses were carried out under programmed conditions, at constant flow rate of 0.6 mL/min, employing
137 ammonium acetate solution 10 mM acidified with 0.05% formic acid (A), and acetonitrile (B) as mobile phase. The
138 total run time was 4 minutes, and the program started with 1 min of 5% A in isocratic conditions; then the percentage of
139 A gradually increased to 60% in 1 min and hold for 0.5 min. Finally, the initial conditions were restored to 5% A in 0.5

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140 min and hold for further 1 min, to equilibrate the column. Samples were maintained at 20°C in the autosampler. The
141 chromatographic system was coupled with a Waters Quattro Premier XE™ triple quadrupole mass spectrometer
142 equipped with an ESCi™ Multi-Mode Ionization Source (Waters Corporation, Milford MA, USA) operating in positive
143 electrospray ionization (ESI+) mode. Analysis were performed in MRM (multiple reaction monitoring) mode,
144 monitoring two transitions for GB and two for the deuterated IS; the selected transitions (and the relative values of CV
145 and CE, respectively) were the following: 118.2 > 59.3 m/z (38 V, 16 eV) and 118.2 > 58.3 m/z (38 V, 23 eV) for GB;
146 127.2 > 68.4 m/z (38 V, 18 eV) and 127.2 > 68.4 m/z (38 V, 27 eV) for D₉-BET. Argon was used as collision gas at a
147 flow of 0.35 mL/min. The instrument settings were: capillary voltage 4.00 kV, source temperature 140 °C, desolvation
148 temperature 325 °C, cone gas 150 L/h and desolvation gas 550 L/h. A Waters MassLynx™ 4.1 software (Waters
149 Corporation, Milford MA, USA) was used to acquire and process data.

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2.4 Method validation

176 The described method was validated considering the guidelines of the Commission Decision 2002/657/EU
177 (Commission Decision 2002). The use of a deuterated IS ensured the quality of data and GB was quantified considering
178 the ratio between its area and that of the IS on matrix-matched calibration curves.

179 Two working solutions were prepared, one for GB and one for the IS, at a concentration of 5000 µg/mL and 100 µg/mL
180 in acetonitrile:water = 95:5, respectively. Linearity was evaluated by matrix-matched calibration curves, prepared each
181 day of validation, spiking 50 mg of clam tissue with a fixed amount of IS (40 µL of IS working solution) and 4
182 increasing levels of GB, as reported in Table 1. The limit of quantification (LOQ) of the method was identified as the
183 lowest point of the calibration curve (2.5 µg/mg). To establish the average endogenous content of GB in Manila clams,
184 an appropriate number of representative blank samples (a total of twenty) were processed and analysed (Commission
185 Decision 2002). The percent standard deviation of the data obtained by the analysis of 20 samples (fortified with the
186 fixed amount of the IS) resulted below 15%; therefore, the mean value of the responses was used to be matched with the
187 zero value of the calibration curve.

188 Trueness and precision of the method were calculated by the analysis of matrix-matched quality control (QC) samples,
189 realised in six replicates for three day of validation: clams samples were fortified with the fixed amount of IS, and at 4
190 µg/mg (QC low), at 6 µg/mg (QC medium) and at 8 µg/mg (QC high) of GB.

191 Trueness, expressed as bias, is the relative difference between the mean measured value and the spiked concentration,
192 and for these concentrations the bias values should be in the range between -20% and +10% (Commission Decision
193 2002).

170 Precision was measured as relative standard deviation to the mean (CV%). Since the mass fraction of this analyte in the
171 target matrix, expressed as a power of 10, is 10^{-6} , values of CV% in within-laboratory reproducibility conditions
172 (different operators, different days) should be lower than 16% (Commission Decision 2002), calculated by the Horwitz
173 equation. As far as repeatability conditions (intra-day analysis) are concerned, CV% values should be lower than 11%,
174 which is two-thirds of the value calculated by the Horwitz equation.

175 The analyte stability in matrix was assayed under different storage conditions. For this purpose two samples fortified at
176 QC medium level were prepared; one was maintained for 24 h in autosampler (bench-top stability) at 20°C and one was
177 subject to freeze-thaw cycles of 1, 2, 4 and 20 weeks. The acceptance criteria for all stability tests were an accuracy of
178 within $\pm 15\%$ (European Medicines Agency 2011). Before the analysis of the frozen samples, the vials containing the
179 extracts were left at room temperature for two hours to obtain a complete thaw of the sample.

180 The presence of a carry-over of the target molecule in the system was assessed by means of six consecutive injections
181 of a solution free of the target compounds, consisting of water:acetonitrile 50:50, after the injection of a calibration
182 curve. The intensity of eventual signals should not be greater than the 20% of those obtained by the injection of the
183 lower point of the calibration curve; likewise, concerning the IS, the signal should not overweight the 5% (European
184 Medicines Agency 2011).

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186 **3. Results and discussion**

187 **3.1 Chromatographic method development**

188 The chromatographic technique, characterised by the use of a normal stationary phase in combination with a reverse
189 mobile phase, is the “Hydrophilic Interaction Liquid Chromatography” (HILIC) (Zhao et al. 2011). This technology
190 provides good retention of strongly polar molecules employing high percentages (more than 50%) of organic solvents
191 (often acetonitrile) in the mobile phase, which are especially compatible with ESI source, due to their low viscosity.
192 HILIC technique therefore provides high performances in terms of sensitivity, selectivity and separation efficiency
193 (Jandera 2011; Zhao et al. 2011). Several authors in the last years exploited this technology for the quantification of GB
194 in biological liquid matrices, including plasma (Bruce et al. 2010; Kirsch et al. 2010), serum (Steuer et al. 2016), urine
195 (Ocque et al. 2015; Zhao et al. 2015), amniotic fluid and cerebrospinal fluid (Kirsch et al. 2010), but also in foods and
196 tissues (Zhao et al. 2011; Xiong et al. 2012), seaweeds (MacKinnon et al. 2010), and cereal products (Bruce et al. 2010;
197 Ross et al. 2014).

198 Also in the present work, the interactions between the HILIC stationary phase and GB and IS allowed a successfully
199 retention of analytes. The mobile phases generally used for GB and related compounds analysis are acetonitrile and
200 aqueous solution with 5-20 mM of ammonium formate or acetate, acidified with formic or acetic acid, to reach a pH

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201 between 3 and 3.5. In order to optimize the chromatographic conditions for GB, 10 mM of ammonium acetate and 10
202 mM of ammonium formate in aqueous solution were tested, but no difference in terms of sensitivity between the two
203 buffers were noted. Regarding pH optimisation, better performances have been reached at values of 3.6, obtained
204 adding 0.05% of formic acid, according to the concentrations used in other studies (Bruce et al. 2010; Kirsch et al.
205 2010; Ocque et al. 2015).

206 The use of optimised mobile phases and programmed conditions employing increasing concentration of water to elute
207 the analytes allowed to achieve narrow and symmetric peak shapes for both GB and IS, in a very short chromatographic
208 run (4 min, including column re-equilibration). The high percentages of acetonitrile (never below 40%) in the ramp also
209 provided high performances in terms of sensitivity due to its high compatibility with ESI source.

211 **3.2 Extraction procedure optimisation**

212 This extraction procedure is the result of the optimization of two published methods, developed by de Zwart *et al.*
213 (2003) and Hefni *et al.* (2015), for the determination of GB in food. The procedure consisted in a simple and rapid
214 liquid-liquid extraction (LLE) method using water as solvent, exploiting the highly water-solubility of the analyte
215 (Lever and Slow 2010). A purification step with dichloromethane resulted necessary to remove non-polar analytes,
216 which could interfere during GB ionization (e.g. phospholipids). Then, a SPE (solid-phase extraction) purification step
217 could be avoided, making the method described simple, rapid and cheap.

218 This extraction procedure was compared with those employed by Koc, *et al.* (2002), Zhao *et al.* (2011) and Xiong *et al.*
219 (2012), to extract GB from foodstuff applying modified versions of the Bligh and Dyer method (Bligh and Dyer 1959).
220 Methanol, as extraction solvent, has been largely used for the analysis of GB in foods (Zeisel et al. 2003; Bruce et al.
221 2010; Ji et al. 2015; Stiboller et al. 2015) or other biological matrices (Li et al. 2010; MacKinnon et al. 2010; Pekkinen
222 et al. 2013; Wang et al. 2014); however, for the purposes of this work, the use of methanol resulted not suitable, since it
223 prevents the optimal two-phases separation between water and the non-polar solvent used for the purification step.

224 Several tests were carried out to establish the amount of sample to be processed; 50 mg of clam pulp were selected as
225 the optimum compromise to obtain an easy sample handling and reasonable concentration of endogenous analyte. The
226 extraction efficiency of different solvent volumes (3, 5 and 10 mL) had also been tested: the addition of 10 mL
227 (suggested by Hefni *et al.* 2015) of water resulted the best choice, as the great analyte content in the target matrix
228 allowed high dilution rates. Moreover, the extension of the extraction time to 30 minutes or the addition of
229 ultrasonication steps did not lead to any notable improvements in recovery rates of the extraction procedure. The
230 sensibility of the technology adopted allowed a further dilution (4:1) with acetonitrile, at the end of the extraction

231 process, with the aim to promote the precipitation of proteins and the dilution of salts; the increasing in the percentage
232 of organic phase in the sample also favours the ionisation in ESI source.

233

234 **3.3 Validation of the method**

235 Validation of the described method for the quantification of GB in *Tapes philippinarum* was performed considering the
236 guidelines of the Commission Decision 2002/657/EC (Commission Decision 2002), with the application of appropriate
237 adjustments, due to the unavoidable presence and the high levels of GB in *Tapes philippinarum*. As a consequence, it
238 was impossible to find a blank matrix; anyway the method developed did not involve the use of any surrogate matrix for
239 the validation procedures.

240 The linearity was evaluated by the injection of matrix-matched calibration curves, prepared as described in Table 1; the
241 regression coefficients (R^2) resulted always above 0.99 for each curve, demonstrating a good linearity of the method.

242 The analysis of quality control samples, fortified as described in section 2.4, reported satisfying results. All the values
243 of precision both in within-laboratory reproducibility conditions and in repeatability conditions (intra-day analysis),
244 were lower than CV% values recommended by Commission Decision 2002/657/EC, and trueness was included in the
245 range of -20% and +10%, as reported in Table 2.

246 The stability of the analyte in the matrix was assessed in two different storage conditions: the former for 24 h in
247 autosampler (bench-top stability) at 20°C and the latter subjected to freeze-thaw cycles of 1, 2, 4 and 20 weeks.

248 The bench-top assay at 20 °C showed a loss of GB concentration of about 25% after 24 hours and the freeze-thaw
249 stability at -18 °C was confirmed only for two cycles (two weeks), according to the limits mentioned in section 2.4
250 ($\pm 15\%$). In general GB shows a good stability even if evaluated in different matrices such as plasma and urine (Holm et
251 al. 2003; Kirsch et al. 2010; Xiong et al. 2012; Midttun et al. 2013), but currently no data on GB stability in extracted
252 Manila clams have been published. Finally, the carry over for this compound was considered irrelevant because the
253 signal at the specific retention time of GB had an acceptable intensity (below 20% of LOQ). Concerning the IS, no
254 signal were detected at its retention time, demonstrating the absence of carry over for this compound.

255 The proposed method was tested on five pools from three different batch of commercial *Tapes philippinarum* samples
256 (n = 15). The results of this test are reported in Table 3; the average level of GB measured in these samples (4.1 $\mu\text{g}/\text{mg}$)
257 is comparable with the level (2.5 $\mu\text{g}/\text{mg}$) assessed by De Zwart *et al.* (2003).

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259 **4. Conclusions**

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260 A rapid and economic method based on UPLC-MS/MS for the detection of GB in *Tapes philippinarum* was developed.
261 The procedure was successfully validated considering the European regulation guidelines. The method proposed results
262 simple and rapid and shows very satisfying performances in terms of linearity, trueness and precision.
263 Currently no other method has been developed and validated for the detection and quantification of GB in *Tapes*
264 *philippinarum* by UPLC-MS/MS. The procedure proposed could be considered a practical and useful tool for the
265 assessment of betaine in molluscs.

266

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269

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371 **Table 1: Calibration curve preparation for the analysis of GB**

Concentration ($\mu\text{g}/\text{mg}$)	$\mu\text{L D}_9\text{-BET}$ (100 $\mu\text{g}/\text{mL}$)	$\mu\text{L BET}$ (5000 $\mu\text{g}/\text{mL}$)
endogenous	40	-
2.5	40	25
5	40	50
7.5	40	75
10	40	100

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Table 2: Trueness and precision results

Fortification level ($\mu\text{g}/\text{mg}$)	Parameter	Day 1	Day 2	Day 2	Reproducibility (Inter-day)
4	Precision (CV%)	3.5	6.0	5.5	4.6
	Trueness (bias%)	-2.6	0.3	-0.6	-1.0
6	Precision (CV%)	5.5	5.6	5.6	5.2
	Trueness (bias%)	3.1	-1.0	-0.4	0.6
8	Precision (CV%)	4.0	0.7	0.5	3.0
	Trueness (bias%)	3.7	-0.5	-1.0	0.7

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