



## **Validation of a confirmatory analytical method for the determination of aflatoxins B1, B2, G1 and G2 in foods and feed materials by HPLC with on-line photochemical derivatization and fluorescence detection**

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**Validation of a confirmatory analytical method for the determination of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> in foods and feed materials by HPLC with on-line photochemical derivatization and fluorescence detection**

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## Abstract

A sensitive and selective analytical method for the simultaneous separation and quantitative determination of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> in foodstuffs and materials for feed has been validated. The method is based on high performance liquid chromatography with on-line post-column photochemical derivatization and fluorescence detection. The chromatographic separation of aflatoxins was accomplished by using a C<sub>18</sub> column eluted with an isocratic mobile phase consisting of water, methanol and acetonitrile. The sample preparation required a simple extraction of aflatoxins with MeOH/H<sub>2</sub>O (80:20, v/v) and a purification step by immunoaffinity column cleanup. The total analysis time, including sample preparation and chromatographic separation, did not exceed 40 min with a run time of 10 min. The on-line photochemical derivatization ensures better results in terms of simplicity, sensitivity and reproducibility with respect to chemical derivatization techniques, and provides an increase of the peak resolution and an extent of automation in comparison with the electrochemical ones. The procedure for the determination of aflatoxins in food samples and cereals for animal consumption was extensively validated following the Regulation (EC) No. 882/2004. Detection limits in wheat bran samples of 0.08 µgkg<sup>-1</sup> for AFB<sub>1</sub>, 0.02 µgkg<sup>-1</sup> for AFB<sub>2</sub>, 0.16 µgkg<sup>-1</sup> for AFG<sub>1</sub> and 0.04 µgkg<sup>-1</sup> for AFG<sub>2</sub> were attained. The method allows high recovery with mean values ranging from 72% to 94% and it satisfies the necessary requirements for sensitivity, linearity, selectivity, precision and ruggedness, demonstrating the conformity of the method with provisions of Regulation (EC) No. 401/2006.

**Keywords:** Aflatoxins, HPLC, photochemical derivatization, validation, Regulation (EC) No. 401/2006, Regulation (EC) No. 882/2004

**Introduction**

Aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> (AFB<sub>1</sub>, AFB<sub>2</sub>, AFG<sub>1</sub> and AFG<sub>2</sub>), secondary metabolites of mould fungi *Aspergillus flavus* and *Aspergillus parasiticus*, are a group of structurally related mycotoxins, which exhibit acute and chronic toxicity including mutagenic, carcinogenic and teratogenic effects in several organisms (Harwig and Munro, 1975, Bullerman, 1979, Dickens and Jones, 1963, Garner and Kingfisher, 1979). The International Agency for Research on Cancer (IARC) classified aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> as group 1 of human carcinogens (IARC, 1993). The widespread occurrence of the *Aspergillus* mould means that several agricultural commodities are vulnerable to contamination with aflatoxins. The storage of these products under high moisture and increased temperature conditions (25–30°C) enhances the natural occurrence of aflatoxins in a great variety of foods for animal and human consumption (Peraica et al., 1999, Eaton and Groopman, 1994), such as cereals, corn, peanuts, pistachios, almonds and beans.

The European Union (EU) has set a maximum level (ML) of 2 µgkg<sup>-1</sup> for AFB<sub>1</sub> and 4 µgkg<sup>-1</sup> for total aflatoxins (B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub>, and G<sub>2</sub>) in nuts, dried fruit and cereals intended for direct human consumption (Regulation (EC) No. 1881/2006). In baby food products, more restrictive limits (0.10 µgkg<sup>-1</sup> for AFB<sub>1</sub>) have been established (Regulation (EC) No. 683/2004). In agreement with the Directive (EC) No. 100/2003, a maximum residue limit of 20 µgkg<sup>-1</sup> for AFB<sub>1</sub> has been fixed in cereals for animal consumption (Italian Ministerial Decree 149/2004, Italian Official Journal n.139, June 2004).

Due to the significant health risks associated with the presence of aflatoxins in foods and to satisfy the rigorous legal requirements too, it is important to have efficient techniques for the detection of aflatoxins in foods and animal feeds. Several procedures for the determination of

aflatoxins have been developed, comprising immunological methods, such as enzyme linked immunosorbent assays (Trucksess and Stack, 1994, Park et al., 1989), and chromatographic methods based on RP-HPLC and fluorescence detection (FLD) with chemical pre- or post-column (Wilson and Romer, 1991, Torres Espinosa et al., 1995, Roch et al., 1992, Saad et al., 1995, Garcia-Villanova et al., 2004, Davis et al., 1981, Tuinstra and Haasnoot, 1983, Niedwetzki and Lach, 1994, Ahmed and Robinson, 1998, Holcomb and Thompson, 1991, Garner et al., 1993, Chan et al., 2004, Va'zquez et al., 1999, Cepeda et al., 1996) or on-line electrochemical (Kok et al., 1986, Kussak et al., 1995, Dorner et al., 1993, Scholten and Spanjer, 1996, Tavčar-Kalcher et al., 2007) derivatization of analytes.

Although ELISA methods are extensively used for rapid qualitative screenings of aflatoxins, they are not useful in providing a definitive confirmation of the toxins and an accurate quantitative determination. The present trend is the use of HPLC for the determination of aflatoxins because of characteristics of specificity, high sensitivity and simplicity of operation. Additionally, the chromatographic determination allows quantifications of each toxin individually, obtaining more information than methods that give only a total quantification of aflatoxins. This is particularly important for food analysis where the determination of AFB<sub>1</sub> is required.

The highly conjugated and rigid aflatoxin moieties give rise to native fluorescence characteristics, therefore small structural modifications can have a strong influence on the fluorescence properties; for instance aflatoxins G<sub>2</sub> and B<sub>2</sub> are more fluorescent than B<sub>1</sub> and G<sub>1</sub> that are required to be converted into more highly fluorescent derivatives. Several methods of derivatization are available, including pre-column treatment with trifluoroacetic acid (TFA) (Garcia-Villanova et al, 2004) and post-column derivatization with iodine (Davis et al., 1981,

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4 98 Tuinstra et al., 1983, Niedwetzki et al., 1994, Ahmed et al., 1998, Holcomb et al., 1991),  
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6 cyclodextrins (Va'zquez et al., 1999, Cepeda et al., 1996) and pyridinium hydrobromide  
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9 100 perbromide (Garner et al., 1993, Chan et al., 2004). However, these methods are laborious and  
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11 present a number of disadvantages, such as handling of toxic reagents, instability of the  
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13 102 derivatives, a low day-to-day reproducibility. An alternative approach is based on post-column  
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15 electrochemically generated bromine (Cepeda et al., 1996, Kok et al., 1986, Kussak et al., 1995,  
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18 104 Dorner et al., 1993, Scholten et al., 1996) that do not give a good chromatographic peak  
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20 resolution and allows a less extent of automation, since any accidental interruption of the mobile  
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22 106 phase flux determines a serious damage to the electrochemical cell. Nowadays, an on-line  
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24 photochemical derivatization system is available (Joshua, 1993, Papadopoulou-Bouraoui et al.  
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27 108 2002, Sobolev and Dorner, 2002, Sobolev, 2007, Waltking et al., 2006, Arranz et al., 2006,  
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29 Zang and Lim, 2005), but its potential has not fully investigated. It has been reported that the  
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32 110 on-line photochemical derivatization coupled to fluorescence detection guarantees an  
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34 enhancement of efficiency and performances of the HPLC methods (Papadopoulou-Bouraoui et  
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36 112 al., 2002, Zang et al., 2005). Differently from chemical pre- and post-column derivatization  
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38 techniques, the photochemical derivatization does not involve any additional chemicals and,  
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41 114 consequently, no auxiliary pump is required, ensuring better results without any control of the  
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43 derivatization reaction. Nevertheless, to the best of our knowledge chromatographic methods for  
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46 116 the determination of aflatoxins, exploiting the photochemical derivatization and fluorescence  
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48 detection, have been never validated according to the recent European Commission guidelines.  
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53 In the present work, the procedure for the determination of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> in foods  
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56 120 and materials for feed, based on immunoaffinity column sample cleanup and liquid  
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58 chromatography coupled to photochemical derivatization and fluorescence detection, has been  
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60 122 submitted to the validation procedure following the Regulation (EC) No. 882/2004. The

validation of the proposed analytical method is required in order to provide accurate and reproducible results within- and inter-official control laboratories, which are involved in the monitoring and risk-assessment studies, as well as in official controls. Through validation procedure, linearity, selectivity, recovery, precision, detection and quantification limits (LODs, LOQs), ruggedness of the method and measurement uncertainty have been evaluated. Furthermore, laboratory performances were tested by taking part in a proficiency test round. The results of the validation procedure demonstrate the conformity of the method of aflatoxins analysis in foods and animal feeds with provisions of Regulation (EC) No. 401/2006, which, as underlined by European Commission Sanco 0895/2007, establishes more specific performance criteria than Decision 657/2002/EC for methods of analysis to be used for official control of mycotoxins in foodstuffs.

## Materials and Methods

**Chemicals.** A standard solution of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> with a total certified concentration of 5 µg mL<sup>-1</sup> corresponding to a concentration of 2.0 µg mL<sup>-1</sup> each for B<sub>1</sub> and G<sub>1</sub> and of 0.5 µg mL<sup>-1</sup> each for B<sub>2</sub> and G<sub>2</sub>, was supplied by Riedel-de Haën (Sigma-Aldrich Laborchemikalien, Seelze, Germany). Water, methanol and acetonitrile of HPLC grade were purchased from Baker (Deventer, Holland). Sodium chloride (≥99.0%), Na<sub>2</sub>HPO<sub>4</sub>·2H<sub>2</sub>O (≥99.0%), NaH<sub>2</sub>PO<sub>4</sub>·H<sub>2</sub>O (≥99.0%) and TWEEN 20® were purchased from Sigma-Aldrich. All chemicals were of ACS grade. A 500 µg L<sup>-1</sup> stock solution of aflatoxins standard, containing 200 µg L<sup>-1</sup> of AFB<sub>1</sub>, 50 µg L<sup>-1</sup> of AFB<sub>2</sub>, 200 µg L<sup>-1</sup> of AFG<sub>1</sub> and 50 µg L<sup>-1</sup> of AFG<sub>2</sub>, were prepared in acetonitrile and stored in amber flask at -20°C up to 6 months. Working standard solutions were prepared by dilution in mobile phase and stored at -20°C when not in use; these solutions were stable for at least 4 weeks. Phosphate buffer salinum (PBS) was prepared by dissolving 9.0 g of sodium chloride, 2.85 g of Na<sub>2</sub>HPO<sub>4</sub>·2H<sub>2</sub>O, 0.55 g of NaH<sub>2</sub>PO<sub>4</sub>·H<sub>2</sub>O and 1.0 mL of TWEEN



20® in 990 mL of water. The pH value was adjusted to 7.2 with concentrated hydrochloric acid or NaOH 1M and the volume made to 1L with water.

**Instrumentation.** Chromatographic separations were performed on a HPLC system, Agilent Technologies SL 1200 Series (Waldbronn, Germany) composed of a binary pump equipped with micro vacuum degasser, thermostated autosampler, column compartment and fluorescence detector (model G1321A). On-line photochemical derivatization was performed using a commercially available system UVE™ LCTech GmbH (Dorfen, Germany) placed between the separation column and the fluorescence detector, which consisted of a 254 nm low-pressure mercury lamp and a 1 mL knitted reaction coil, fitted around the UV lamp. All the separations were performed by using a ZORBAX Eclipse XDB C<sub>18</sub> column (150 × 4.6 mm i.d., particle size 5 µm, Agilent Technologies) operating at a flow-rate of 1.0 mLmin<sup>-1</sup> in isocratic elution with a mixture of water, methanol and acetonitrile (55:15:30, v/v/v). The injection volume was 20 µL and the column temperature was set at 40°C. The fluorescence detection was carried out at a  $\lambda_{\text{exc}}$  and  $\lambda_{\text{em}}$  of 365 and 435 nm, respectively. The system was interfaced, via network chromatographic software (Agilent ChemStation), to a personal computer for instrumentation control, data acquisition and processing.

**Sample preparation.** Samples of wheat bran, almonds and pistachios were bought in local stores; durum wheat, maize and oats were supplied by farms chosen among the major cereal producers in the province of Foggia (Italy). Both sample extraction and cleanup procedure were those recommended by LCTech and slightly modified in order to simplify the analytical protocol and to reduce reagents and chemical wastes. The method did not require vacuum or pumping devices ensuring better recoveries and reproducibility. For each matrix, from a sample weight of 1 kg, an amount of 15 g of ground sample was suspended in 30 mL of 80 % methanol and vortexed for few min. For the validation measurements, samples were spiked, prior to the extraction, with the proper amounts of mixed aflatoxin standard solutions to give required

concentrations. After filtration with paper (Whatman No. 40), 2 mL of the mixture were added to 8 mL of PBS solution and passed through the immunoaffinity columns Aflaclean™ (LCTech GmbH, Dorfen, Germany) for sample clean-up. After washing with 10 mL of water, the fraction containing the aflatoxins was slowly eluted with 2 mL of methanol by gravity at a flow rate lower than of 0.5 mL min<sup>-1</sup>. The eluate was evaporated to dryness at 40 °C under nitrogen stream (Dubnof Bath BSD/D). Finally, the residue was solubilized in 2 mL of the mobile phase, filtered by an Anotop 10 LC (0.2 µm, 10 mm, Whatman) and then injected. The analytical procedure resulted in a 2-fold dilution of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub>, evaluated against a known concentration added to a blank real sample. The stability of purified extracts was high enough to allow autosampler overnight injections. No significant change in concentration or purity of aflatoxins within 8 hours of analysis was observed.

**Validation procedure.** In consequence of different legal limits for aflatoxins in foodstuffs and cereals for animal consumption, different sets of standard solutions and spiked samples were used for foodstuffs (wheat bran, almonds and pistachios) and materials for feed (durum wheat, maize and oats). The linearity test in foodstuffs was performed by three series of analyses on three different days, by injecting four standard solutions of aflatoxins B<sub>1</sub> and G<sub>1</sub> each at concentrations of 0.25, 0.5, 1.0 and 2.0 µg L<sup>-1</sup> and aflatoxins B<sub>2</sub> and G<sub>2</sub> each at concentrations of 0.0625, 0.125, 0.25 and 0.5 µg L<sup>-1</sup>. Likewise, method linearity in feed materials was determined by using working standard solutions of AFB<sub>1</sub> at concentration of 2.5, 5.0, 10 and 20 µg L<sup>-1</sup>. The method selectivity was tested by the analysis of 20 independent blank samples of foods (7 of wheat bran, 7 of almonds and 6 of pistachios) and 20 samples of cereals (7 of durum wheat, 7 of maize and 6 of oats), found negative by ELISA screening. The absence of interfering peaks in the retention time-window of interest was checked for each analyte within the ± 2.5% retention time range. Precision, recovery and both detection and quantification limits of the method were determined by performing tests on three sets of blank wheat bran samples (six replicates each)

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4 198 fortified with AFB<sub>1</sub> at concentration of 0.5, 1.0 and 1.5 times the ML in foodstuffs (i.e., 1.0, 2.0  
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6 and 3.0  $\mu\text{gkg}^{-1}$ ) and aflatoxins B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> at concentration of 0.625, 1.25 e 1.875 times the  
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9 200 ML of the sum of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> (i.e., 1.0, 2.0 and 3.0  $\mu\text{gkg}^{-1}$  for B<sub>1</sub> and G<sub>1</sub>, and  
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11 0.25, 0.5 and 0.75  $\mu\text{gkg}^{-1}$  for B<sub>2</sub> and G<sub>2</sub>). As far as the analysis of feed materials is concerned,  
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14 202 only two sets of blank durum wheat samples (six replicates each) fortified with AFB<sub>1</sub> at  
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16 concentration of 0.5, 1.0 and 1.5 times the ML in cereals for animals (i.e., 10, 20 and 30  $\mu\text{gkg}^{-1}$ )  
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19 204 were analysed. The experiments, corresponding to a total number of 54 and 36 for food samples  
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21 and animal feed materials, respectively, were performed in different days with the same  
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23 206 instruments but different operators.

## 27 208 **Results and Discussion**

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30 **Method Validation.** The proposed method has been validated according to Regulation (EC) No.  
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32 210 882/2004, a document about official controls performed to ensure the verification of compliance  
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34 with feed and food laws, animal health and animal welfare rules, which demonstrates the  
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37 212 conformity of the analytical performances with criteria established in Regulation (EC) No.  
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39 401/2006. Therefore, through validation procedure, linearity, selectivity, recovery, precision,  
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42 214 detection and quantification limits, ruggedness of the method and measurement uncertainty have  
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44 been evaluated.

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46 216 **Selectivity towards interferences.** Figure 1 shows, as an example, the fluorescence enhancement  
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48 attained by on-line photochemical derivatization for a wheat bran sample fortified with AFB<sub>1</sub>  
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51 218 and AFG<sub>1</sub> at 3.0  $\mu\text{gkg}^{-1}$  and AFB<sub>2</sub> and AFG<sub>2</sub> at 0.75  $\mu\text{gkg}^{-1}$ . Through the post-column UV  
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53 irradiation, AFB<sub>1</sub> and AFG<sub>1</sub> are converted by the reaction with water contained in the mobile  
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56 220 phase to fluorescent hemiacetals, which are similar compounds to those obtained by  
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58 derivatization with TFA (Garcia-Villanova et al., 2004). This photochemical modification  
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222 determines an increase of the response sensitivity of AFB<sub>1</sub> and AFG<sub>1</sub>, while a very slight

modification of signal intensities has been observed for AFB<sub>2</sub> and AFG<sub>2</sub>. Use of both the immunoaffinity sample cleanup and post-column photochemical derivatization permitted an efficient elimination of possible endogenous matrix interfering substances. In pre-validation experiments the probable interfering compounds, ochratoxin A and fumonisins B<sub>1</sub> and B<sub>2</sub>, common contaminants of cereals, nuts and dried fruit, have been tested. These compounds showed retention times significantly different from those of aflatoxins or undetectable signals under the adopted experimental conditions. Chromatograms of Figure 2, obtained for blank and spiked samples with aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub>, demonstrate the selectivity of the method toward other naturally present compounds, since at the retention times of the aflatoxins no interfering peaks were observed.

**Calibration curves and limits of detection and quantification.** The goodness-of-fit of the data to the calibration curve is obtained in terms of response factor distribution (signal-to-concentration ratio,  $y_i/x_i$ ) whose reference range is  $y/x_{\text{mean}} \pm 10\%$ . Furthermore, any systematic instrumental bias can be ruled out since the intercept includes the zero value at 95% confidence level. The calibration parameters evaluated for each aflatoxin by using standard solutions are reported in Table 1. Limits of detection and quantification were calculated according to the following equations (Miller and Miller, 1993):  $\text{LOD} = 3.3 s_a/b$  and  $\text{LOQ} = 10 s_a/b$ , where  $s_a$  is the standard deviation of the intercept and  $b$  is the slope of the regression line, obtained from the calibration curve. The limit of quantification for AFB<sub>1</sub> of 0.11  $\mu\text{gL}^{-1}$  corresponding to a value of 0.22  $\mu\text{gkg}^{-1}$  in matrix is satisfactory with respect to the allowed maximum content of 2  $\mu\text{gkg}^{-1}$  (Regulation (EC) No. 1881/2006). Fit of the data to the calibration curve of AFB<sub>1</sub> in cereals for feeds gave the linear regression equation  $y = (1.002 \pm 0.006) x + (0.09 \pm 0.06)$  with a correlation coefficient of 0.9999, where  $y$  is the peak area expressed in luminescence unit (LU) and  $x$  is the concentration of AFB<sub>1</sub> in  $\mu\text{gL}^{-1}$ . The obtained limit of quantification of 1.2  $\mu\text{gkg}^{-1}$  is noticeably

lower than the maximum content of  $20 \mu\text{gkg}^{-1}$  set for feed materials (Italian Ministerial Decree 149/2004, Italian Official Journal n.139, June 2004).

**Precision and recovery.** Precision results have been previously processed by the Shapiro–Wilk test to verify the normal distribution. Afterwards, ANOVA one way test was performed in order to verify the homogeneity of the concentration mean values evaluated on three different days. In Table 2 and 3 the results of repeatability ( $\text{RSD}_r$ ) and within-laboratory reproducibility ( $\text{RSD}_R$ ) are given for each aflatoxin at the three contamination levels in spiked wheat bran samples. Furthermore, Table 4 shows the results of repeatability and within-laboratory reproducibility determined for  $\text{AFB}_1$  in spiked durum wheat (cereal for feeds). Regulation (EC) No. 401/2006 issued that the recommended values of experimental RSD for each concentration level must be lower or equal than value derived by Horwitz equation, which provides the expected  $\text{RSD}\%$  only on the basis of the concentration, independently of the matrix and analytical method used. Nevertheless, for mass fractions lower than  $120 \mu\text{gkg}^{-1}$ , the  $\text{RSD}\%$  can be predicted in a more restrictive manner by the Thompson equation (Thompson, 2000), which provides a recommended value of  $\text{RSD}_r$  of 15 % and a reference inter-laboratory reproducibility of 23%. As can be seen in Table 2 and 4,  $\text{RSD}_r$  % values are in agreement with the calculated repeatability by Thompson equation. In absence of within-laboratory reproducibility reference values, our experimental data have been compared with the repeatability maximum permitted limit of 30%, which has been calculated as 2 fold the  $\text{RSD}_r$  recommended value, by using a similar approach proposed for the calculation of the maximum permitted value of Horwitz  $\text{RSD}_R$  (Regulation (EC) No. 401/2006). As shown in Table 3, all  $\text{RSD}_R$  values resulted well below of 30%, and even in agreement with the repeatability recommended values of 15%, apart from  $\text{AFG}_2$ . In Table 5 mean recoveries of aflatoxins evaluated at each fortification level in spiked wheat bran and durum wheat samples are reported. As can be noticed, the recovery values obtained for

food products ranged from 76.4 to 94.6% for aflatoxins B<sub>1</sub> and G<sub>1</sub> and from 79.5 to 92.8% for aflatoxins B<sub>2</sub> and G<sub>2</sub>. These results are in agreement with Regulation (EC) No. 401/2006 that establishes recoveries in the range 70-110% and 50-120% for concentrations in the range 1-10  $\mu\text{gkg}^{-1}$  and less than 1  $\mu\text{gkg}^{-1}$ , respectively. In the analysis of cereals for animal feeds, mean recovery data higher than 72.6 % were obtained. It was not possible to compare experimental mean recoveries with reference values since so far no legal criteria have been set for these matrices.

Assessment of LODs and LOQs in real samples has been calculated for each analyte by mean the fit of the data to calibration curves obtained by plotting the fluorescence signals of 18 spiked wheat bran samples (six replicates evaluated in the three different working sessions at each validation level) as a function of the nominal fortification level. LOD and LOQ values, which have been calculated by using the same equations previously described, ranged from 0.06 to 0.3  $\mu\text{gkg}^{-1}$  and from 0.2 to 0.8  $\mu\text{gkg}^{-1}$ , respectively, with LOD and LOQ for AFB<sub>1</sub> of 0.2  $\mu\text{gkg}^{-1}$  and 0.6  $\mu\text{gkg}^{-1}$ , respectively. As expected, taking into account the loss of analyte during extraction and cleanup steps, LODs and LOQs are higher than those determined by calibration curves of standard solutions, but still considerably lower than legal limits.

**Ruggedness (major changes).** The method ruggedness under conditions of major changes was evaluated by using the Youden experimental design as reported elsewhere (Muscarella et al., 2007). Two independent Youden tests were performed for different sets of real samples: almonds and pistachios (foodstuffs) and maize and oats (feed materials) spiked at the AFB<sub>1</sub> maximum level. The seven factors chosen as variables for the Youden test were the matrix and six fictitious factors; the use of a fictitious variable means no variation of analysis conditions. In this case the Youden experimental design requires eight independent experiments: four with the matrix of validation (e.g. wheat bran and durum wheat) and four with each testing matrices (almonds, pistachios, maize and oats). Analysis of foods for human consumption gave a

calculated standard deviation of difference  $S_{Di}$  ( $0.09 \mu\text{gkg}^{-1}$  for almonds and pistachios) lower than the estimated method precision at the ML ( $0.21 \mu\text{gkg}^{-1}$ ). Similar considerations are valid for maize sample whose standard deviation of difference  $S_{Di}$  ( $1.40 \mu\text{gkg}^{-1}$ ) resulted slightly lower than method precision ( $1.45 \mu\text{gkg}^{-1}$ ). In the case of oats matrix, test F (performed at  $n-1$  degrees of freedom and 95% confidence level) demonstrated that  $S_{Di}$  ( $2.36 \mu\text{gkg}^{-1}$ ) was not statistically different from the reproducibility standard deviation ( $1.45 \mu\text{gkg}^{-1}$ ) at the ML, therefore the variation of the matrix has no effect on the method performances.

**Measurement uncertainty.** The evaluation of uncertainty of analytical results is compulsory for laboratories accredited according to ISO 17025 (UNI CEI EN ISO/IEC 17025/2000), and several methods for the determination of this parameter have been proposed (EURACHEM Guide, 1995; EURACHEM/CITAC GUIDE CG 4, 2000; Nordic Committee on Food Analysis, NMKL, 2003). In this work we have used the bottom-up method together with validation data obtained from each step of the analytical procedure (Hund et al., 2001). On the basis of uncertainties propagation law, for each aflatoxin the concentration relative uncertainty has been calculated by the equation:

$$\bar{u} = \sqrt{(\bar{u}(C))^2 + (\bar{u}(V_f))^2 + (\bar{u}(w))^2}$$

where  $\bar{u}$  indicates the relative uncertainty,  $C$  is the analyte concentration in the sample,  $V_f$  is the volume of the final extract, and  $w$  is the sample weight. The determination of  $\bar{u}$  has been performed by considering four sources of uncertainty: (a) preparation of the standard; (b) method reproducibility; (c) method recovery; (d) calibration curve.

A relative expanded measurement uncertainty was calculated by using a coverage factor  $k$  of 2, corresponding approximately to a 95% confidence level (Nordic Committee on Food Analysis, NMKL, 2003) obtaining values of 8.4%, 12.9 %, 9.9 % and 14.2 % for aflatoxins  $B_1$ ,  $B_2$ ,  $G_1$  and  $G_2$ , in foodstuffs. In the validation on cereals for animal feeds, the relative expanded measurement uncertainty calculated for  $AFB_1$  was 7.6 %. These results were compared with the



uncertainty function (Uf), reported in the Regulation (EC) No. 401/2006, to evaluate if the method of analysis is “fit-for-purpose”. This function, which gives the acceptable maximum uncertainty level of the method, is calculated by the following equation:

$$U_f = \sqrt{\left[\left(\frac{LOD}{2}\right)^2 + (\alpha C)^2\right]}$$

where C is the concentration of interest and  $\alpha$  is a C dependent constant factor. Measurement uncertainties evaluated for AFB<sub>1</sub> in food samples and feed materials (8.4% and 7.6%, respectively) are considerably lower than corresponding Uf values (20% at C = 2  $\mu\text{gkg}^{-1}$ ,  $\alpha$  = 0.2 and 21 % at C = 20  $\mu\text{gkg}^{-1}$ ,  $\alpha$  = 0.2, respectively). The above results confirm that method is “fit-for-purpose”.

**Proficiency test round.** The proficiency test round was organised by Milk Standard Laboratory of A.I.A. (Italian Association of Breeders) in April 2007. Three unknown maize flour samples were analyzed in duplicate and the results were assessed in terms of Z-score, as calculated by the proficiency test organizer. The Z-scores obtained in the A.I.A. ring test performed on unknown maize flour samples ( $Z_1=-0.849$ ,  $Z_2=-0.043$ ,  $Z_3=-0.040$ ) and the value of the laboratory Z-score ( $Z_{\text{LAB}}=-0.322$ ) were all below the reference value of 1, proving the technical competence of the laboratory and the method reliability.

## Conclusions

A fast, reliable and automated method for the simultaneous determination of aflatoxins in a variety of foods and animal feed materials, based on HPLC-FLD with post-column photochemical derivatization, has been validated. Photochemical derivatization results reagentless, no time consuming and easy to use, ensuring high sensitivity and reproducibility without any control of the derivatization step with respect to chemical derivatization systems, and it provides a better peak resolution and an extent of automation in comparison with the



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346 electrochemical ones. The accurate and highly sensitive proposed method offers several  
advantages in terms of simplicity, rapidity and efficiency. In fact, the results of the method  
348 validation, performed according to Regulation (EC) No. 882/2004, demonstrate the method  
conformity with provisions of Regulation (EC) No. 401/2006 and indicate that the procedure  
350 can be successfully applied for accurate confirmation analyses. The expanded measurement  
uncertainties and excellent results achieved in a proficiency test round confirmed the laboratory  
352 technical competence and the method reliability in the determination of aflatoxins in real  
samples, with the accuracy level corresponding to the requirements of the recent European  
354 regulation. Therefore, the proposed method is well suited to satisfy the demands for accurate  
and sensitive detection of aflatoxins with minimal sample preparation and cleanup steps.

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**REFERENCES**

- Ahmed YA, Robinson RK. 1998. Selection of a Suitable Method for Analysis of Aflatoxins in Date Fruits. *J. Agric. Food Chem.* 46(2):580-584.
- Arranz I, Sizoo E, Van Egmond H, Kroeger K, Legarda TM, Burdaspal P, Reif K, Stroka J. 2006. Determination of Aflatoxin B<sub>1</sub> in Medical Herbs: Interlaboratory Study. *J. AOAC Int.* 89(3):595-605.
- Bullerman LB. 1979. Significance of Mycotoxins to Food Safety and Human Health. *J. Food Protect.* 42(1):65-86.
- Cepeda A, Franco CM, Fente CA, Vázquez BI, Rodríguez JR, Prognon P, Mahuzier G. 1996. Postcolumn excitation of aflatoxins using cyclodextrins in liquid chromatography for food analysis. *J. Chromatogr. A*, 721(1):69–74.
- Chan D, MacDonald SJ, Boughtflower V, Brereton P. 2004. Simultaneous determination of aflatoxins and ochratoxin A in food using a fully automated immunoaffinity column clean-up and liquid chromatography–fluorescence detection. *J. Chromatogr. A*. 1059:13-16.
- Davis ND, Guy ML, Diener U.L. 1981. Improved fluorometric-iodine method for determination of aflatoxin in corn. *J. AOAC Int.* 64(5):1974-1976.
- Dickens F, Jones HE. 1963. The carcinogenic action of aflatoxin after its subcutaneous injection in the rat. *Brit. J. Cancer.* 17:691–698.
- Dorner JW, Blankenship PD, Cole RJ. 1993. Performance of two immunochemical assays in the analysis of peanuts for aflatoxin at 37 field laboratories. *J. AOAC Int.* 76:637-643.
- Eaton DL, Groopman JD. 1994. *The Toxicology of Aflatoxins*. San Diego: Academic Press.
- EURACHEM Guide. 1995. *Quantifying Uncertainty in Analytical Measurement*. 1<sup>st</sup> ed. Ellison SLR, Rosslein M, Williams A. Eds.

- EURACHEM/CITAC GUIDE CG 4. 2000. Quantifying Uncertainty in Analytical Measurement. 2<sup>nd</sup> ed. Ellison SLR, Rosslein M, Williams A. Eds.
- European Commission. Regulation (EC) No. 1881/2006. 19 December 2006. Off. J. European Union. L364:5-24.
- European Commission. Regulation (EC) No. 683/2004. 13 April 2004. Off. J. European Union. L106:3-5.
- European Commission. Regulation (EC) No. 882/2004. 29 April 2004. Off. J. European Union. L165:1–141.
- European Commission. Regulation (EC) No. 401/2006. 23 February 2006, Off. J. European Union. L70:12–34.
- European Commission. Health & Consumer Protection Directorate-General, SANCO/0895/2007. Guidelines for the implementation of Decision 2002/657/ec regarding some contaminants (mycotoxins, dioxins and dioxin-like PCBs and heavy metals).
- European Commission. Decision (EC) No. 657/2002. 12 August 2002. Off. J. European Union L221:8–36.
- European Commission. Directive (EC) No. 100/2003. 31 October 2003. Off. J. European Union. L285:33-37.
- Garner RC, Kingfisher CN. 1979. Chemical Carcinogens and DNA. (Vol. 1). Grover PL Ed. Boca Raton: CRC Press.
- Garner RC, Whattam MW, Taylor PJL, Stow MW. 1993. Analysis of United Kingdom purchased spices for aflatoxins using an immunoaffinity column clean-up procedure followed by high-performance liquid chromatographic analysis and post-column derivatization with pyridinium bromide perbromide. J. Chromatogr. 648:485-490.

- 408 Garcia-Villanova RJ, Cordon C, Gonzales Paramas AM, Aparicio P, Garcia Rosales ME. 2004. Simultaneous Immunoaffinity Column Cleanup and HPLC Analysis of Aflatoxins and Ochratoxin A in Spanish Bee Pollen. *J. Agric. Food Chem.* 52:7235-7239.
- 410 Harwig J, Munro IC. 1975. Mycotoxins of possible importance in diseases of Canadian farm animals. *Can. Vet. J.* 16(5):125-141.
- 412 Holcomb M, Thompson HC. 1991. Analysis of Aflatoxins (B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub>, and G<sub>2</sub>) in Rodent Feed by HPLC Using Postcolumn Derivatization and Fluorescence Detection. *J. Agric. Food Chem.* 39:137-140.
- 414 Hund E, Massart DL, Smeyers-Verbeke J. 2001. Operational definitions of uncertainty. *TrAC.* 20(8):394-406.
- 416 International Agency for Research on Cancer (IARC). Lyon 1993. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. 56:245-362.
- 418 Italian Ministerial Decree 149/2004. June 2004. *Ital. Off. J.* 139:14-18.
- 420 Joshua H. 1993. Determination of aflatoxins by reversed-phase high-performance liquid chromatography with post-column in-line photochemical derivatization and fluorescence detection. *J. Chromatogr. A.* 654(2):247-254.
- 422 Kok WT, Van Neer TCH, Traag WA, Tuinstra LGMT. 1986. Determination of aflatoxins in cattle feed by liquid chromatography and post-column derivatization with electrochemically generated bromine. *J. Chromatogr.* 367(1):231-236.
- 424 Kussak A, Andersson B, Andersson K. 1995. Determination of Aflatoxins in Hot Chilli Products by Matrix Solid-Phase Dispersion and Liquid Chromatography. *J. Chromatogr. A.* 708(1):55-60.
- 428 Miller JC, Miller JN. 1993. *Statistics for Analytical Chemistry*. 3<sup>rd</sup> ed. New York:Ellis Horwood PTR Prentice-Hall.
- 430

- 432 Muscarella M, Lo Magro S, Palermo C, Centonze D. 2007. Validation according to European  
Commission Decision 2002/657/EC of a confirmatory method for aflatoxin M<sub>1</sub> in milk based on  
434 immunoaffinity columns and high performance liquid chromatography with fluorescence  
detection. *Anal. Chim. Acta.* 594:257-264.
- 436 Niedwetzki G, Lach G. 1994. Determination of aflatoxins in food by use of an automatic work  
station. *J. Chromatogr. A.* 661:175-180.
- 438 Nordic Committee on Food Analysis (NMKL). 2003. Estimation and expression of  
measurement uncertainty in chemical analysis, 2<sup>nd</sup> ed. NMKL Secretariat. Finland procedure  
440 No. 5.
- Papadopoulou-Bouraoui A, Stroka J, Anklaam E. 2002. Comparison of Two Post-Column  
442 Derivatization Systems, Ultraviolet Irradiation and Electrochemical Determination. *J. AOAC*  
*Int.* 85:411-416.
- 444 Park DL, Miller BM, Hart LP, Yang G, McVey J, Page SW, Pestka J, Brown LH. 1989.  
Enzyme-linked immunosorbent assay for screening aflatoxin B<sub>1</sub> in cottonseed products and  
446 mixed feed: collaborative study. *J. AOAC.* 72(2):326-332.
- Peraica M, Radić B, Lucić A, Pavlović M. 1999. Toxic effects of mycotoxins in humans.  
448 *Bulletin of World Health Organization.* 77:754–766.
- Roch OG, Blunden G, Coker RD, Nawaz S. 1992. The development and validation of a solid  
450 phase extraction/HPLC method for the determination of aflatoxins in groundnut meal  
*Chromatographia.* 33:208-212.
- 452 Saad AM, Abdelgadir M, Moss M.O. 1995. Exposure of infants to aflatoxin M<sub>1</sub> from mothers'  
breast milk in Abu Dhabi, UAE. *Food Addit. Contam.* 12(2):225-261.
- 454 Scholten JM, Spanjer MC. 1996. Determination of Aflatoxin B<sub>1</sub> in Pistachio Kernels and Shells.  
*J. AOAC Int.* 79(6):1360-1364.

- 456 Sobolev VS, Dorner JW. 2002. Cleanup Procedure for Determination of Aflatoxins in Major  
Agricultural Commodities by Liquid Chromatography. *J. AOAC Int.* 85(3):642-645.
- 458 Sobolev VS. 2007. Simple, Rapid, and Inexpensive Cleanup Method for Quantitation of  
Aflatoxins in Important Agricultural Products by HPLC. *J. Agric. Food Chem.* 55:2136-2141.
- 460 Tavčar-Kalcher G, Vrtač K, Pestešek U, Vengušt A. 2007. Validation of the procedure for the  
determination of aflatoxin B<sub>1</sub> in animal liver using immunoaffinity columns and liquid  
462 chromatography with postcolumn derivatization and fluorescence detection. *Food Control.*  
18(4):333-337.
- 464 Thompson M. 2000. Recent trends in inter-laboratory precision at ppb and sub-ppb  
concentrations in relation to fitness for purpose criteria in proficiency testing. *Analyst.* 125:385–  
466 386.
- Torres Espinosa E, Acuna Askar K, Naccha Torres LR, Montoya Olvera R, Castrellon Santa  
Anna JP. 1995. Quantification of aflatoxins in corn distributed in the city of Monterrey, Mexico.  
468 *Food Addit. Contam.* 12(3):383-386.
- 470 Trucksess MW, Stack ME. 1994. Enzyme-linked immunosorbent assay of total aflatoxins B<sub>1</sub>,  
B<sub>2</sub>, and G<sub>1</sub> in corn: follow-up collaborative study. *J. AOAC Int.* 77(3):655–658.
- 472 Tuinstra LGMT, Haasnoot W. 1983. Rapid determination of aflatoxin B<sub>1</sub> in dutch feeding stuffs  
by high-performance liquid chromatography and post-column derivatization. *J. Chromatogr. A.*  
474 282:457-462.
- UNI CEI EN ISO/IEC 17025. 2000.
- 476 Vázquez BI, Fente CA, Franco CM, Cepeda A, Mahuzier G, Prognon P. 1999. Preliminary  
study on fluorimetric detection of aflatoxins Q<sub>1</sub>, P<sub>1</sub> and B<sub>1</sub> using heptakis-di-O-methyl-β-  
478 cyclodextrin as post-column HPLC reagent. *Anal. Commun.* 36:5-7.

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57  
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Waltking AE, Wilson D, Chan D, Dunn E, Humphries J, Kandler H, Sizoo E, Wilson D. 2006.  
Liquid Chromatographic Analysis of Aflatoxin Using Post-Column Photochemical  
Derivatization: Collaborative Study. J. AOAC Int. 89(3):678-692.  
Wilson TJ, Romer TR. 1991. Use of MycoSep multifunctional cleanup column for liquid  
chromatographic determination of aflatoxin in agricultural product J. AOAC. 74(6):951-956.  
Zang LH, Lim JK. 2005. Hitachi HPLC aflatoxin photochemical post-column derivatization.  
LC-GC North America. 23(suppl. 1):47.

**FIGURE CAPTIONS**

**Figure 1.** Chromatograms of a wheat bran sample spiked with AFB<sub>1</sub> and AFG<sub>1</sub> at 3.0 µgkg<sup>-1</sup> and AFB<sub>2</sub> and AFG<sub>2</sub> at 0.75 µgkg<sup>-1</sup>. A) with and B) without on-line photochemical derivation. Separation carried out by a ZORBAX Eclipse XDB C<sub>18</sub> column eluted with a mixture of water, methanol and acetonitrile 55:15:30 (v/v) at a flow rate of 1.0 mLmin<sup>-1</sup>; column temperature 40°C; injected volume: 20 µL; λ<sub>exc</sub> 365 nm and λ<sub>em</sub> 435 nm.

**Figure 2.** Chromatograms of a) blank samples and b) spiked samples of almonds (A), pistachios (B), maize (C) and oats (D). Almonds and pistachios samples have been fortified with AFB<sub>1</sub> and AFG<sub>1</sub> at 2.0 µgkg<sup>-1</sup>, and AFB<sub>2</sub> and AFG<sub>2</sub> at 0.5 µgkg<sup>-1</sup>. Maize and oats samples have been fortified with AFB<sub>1</sub> and AFG<sub>1</sub> at 20 µgkg<sup>-1</sup>, and AFB<sub>2</sub> and AFG<sub>2</sub> at 5 µgkg<sup>-1</sup>. Experimental conditions as reported in Figure. 1.



Validation of a confirmatory analytical method for the determination of aflatoxins B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub> in foods and feed ...

**Table 1.** Performance parameters for aflatoxins in foodstuffs.

$y = a + bx^a$					
Aflatoxin	$b \pm SD$	$a \pm SD$	$r^b$	LOD <sup>c</sup>	LOQ <sup>c</sup>
B <sub>1</sub>	0.87 ± 0.01	0.02 ± 0.01	0.9998	0.04	0.11
B <sub>2</sub>	2.31 ± 0.04	0.02 ± 0.01	0.9996	0.01	0.04
G <sub>1</sub>	0.368 ± 0.009	0.014 ± 0.009	0.9991	0.08	0.24
G <sub>2</sub>	0.87 ± 0.01	0.005 ± 0.004	0.9996	0.02	0.05

<sup>a</sup> y is the signal in lumiscence unit (LU); x is the value of concentration in µg L<sup>-1</sup>. <sup>b</sup> Correlation coefficient. <sup>c</sup> Values expressed in µg L<sup>-1</sup>.

**Table 2.** Repeatability for the determination of aflatoxins in spiked wheat bran samples.

Aflatoxin	Operator	Contamination Level ( $\mu\text{g kg}^{-1}$ )	Determined Concentration Mean $\pm$ SD (n = 6)	RSD <sub>r</sub> <sup>a</sup> (%)
<b>B<sub>1</sub></b>	1	1	1.05 $\pm$ 0.04	3.5
	2		1.0 $\pm$ 0.1	9.8
	3		1.05 $\pm$ 0.06	5.5
	1	2	1.9 $\pm$ 0.1	7.1
	2		2.0 $\pm$ 0.2	10
	3		1.9 $\pm$ 0.1	4.9
	1	3	3.05 $\pm$ 0.14	4.8
	2		3.00 $\pm$ 0.08	2.7
	3		3.1 $\pm$ 0.3	9.5
<b>B<sub>2</sub></b>	1	0.25	0.27 $\pm$ 0.06	11
	2		0.25 $\pm$ 0.02	9.1
	3		0.26 $\pm$ 0.03	10
	1	0.50	0.46 $\pm$ 0.03	7.0
	2		0.49 $\pm$ 0.05	9.8
	3		0.47 $\pm$ 0.03	5.9
	1	0.75	0.77 $\pm$ 0.06	7.4
	2		0.75 $\pm$ 0.02	3.0
	3		0.76 $\pm$ 0.07	9.6
<b>G<sub>1</sub></b>	1	1	1.10 $\pm$ 0.08	7.7
	2		1.0 $\pm$ 0.1	10
	3		1.0 $\pm$ 0.1	9.2
	1	2	1.8 $\pm$ 0.2	11
	2		2.0 $\pm$ 0.2	9.0
	3		1.9 $\pm$ 0.1	6.2
	1	3	3.1 $\pm$ 0.2	7.0
	2		3.0 $\pm$ 0.1	4.4
	3		3.0 $\pm$ 0.3	9.2
<b>G<sub>2</sub></b>	1	0.25	0.27 $\pm$ 0.02	8.8
	2		0.24 $\pm$ 0.04	15
	3		0.27 $\pm$ 0.04	15
	1	0.50	0.46 $\pm$ 0.06	13
	2		0.51 $\pm$ 0.07	14
	3		0.47 $\pm$ 0.05	11
	1	0.75	0.77 $\pm$ 0.07	9.0
	2		0.74 $\pm$ 0.05	6.6
	3		0.77 $\pm$ 0.08	11

<sup>a</sup> Relative standard deviation under repeatability conditions.

**Table 3.** Within-laboratory reproducibility for the determination of aflatoxins in spiked wheat bran samples.

Aflatoxin	Contamination Level	Determined Concentration	RSD <sub>R</sub> <sup>a</sup>
	(µg kg <sup>-1</sup> )	Mean ± SD (n = 18)	(%)
B <sub>1</sub>	1	1.0 ± 0.1	9.9
	2	1.9 ± 0.2	11
	3	3.0 ± 0.2	6.8
B <sub>2</sub>	0.25	0.26 ± 0.03	12
	0.50	0.47 ± 0.05	11
	0.75	0.76 ± 0.06	7.6
G <sub>1</sub>	1	1.05 ± 0.15	14
	2	1.9 ± 0.3	15
	3	3.0 ± 0.2	8.1
G <sub>2</sub>	0.25	0.26 ± 0.05	20
	0.50	0.48 ± 0.09	19
	0.75	0.76 ± 0.08	10

<sup>a</sup> RSD<sub>R</sub>, relative standard deviation under within-laboratory reproducibility conditions.

**Table 4.** Repeatability and within-laboratory reproducibility for the determination of aflatoxin B<sub>1</sub> in spiked durum wheat samples.

Aflatoxin	Contamination Level	Operator	Determined Concentration	RSD <sup>a</sup>
	(µg kg <sup>-1</sup> )		Mean ± SD	(%)
	<i>Repeatability (n = 6)</i>			
B <sub>1</sub>	10	1	10 ± 1	10
		2	10.0 ± 0.8	7.9
	20	1	20 ± 1	6.1
		2	20.0 ± 1.5	7.4
	30	1	29.8 ± 1.6	5.2
		2	30 ± 2	5.7
	<i>Within-laboratory Reproducibility (n = 12)</i>			
B <sub>1</sub>	10		9.9 ± 0.9	9.6
	20		20.2 ± 1.5	7.2
	30		29.9 ± 1.6	5.5

<sup>a</sup> RSD, relative standard deviation under repeatability (RSD<sub>r</sub>) and within-laboratory reproducibility (RSD<sub>R</sub>) conditions.

**Table 5.** Recovery of aflatoxins in spiked wheat bran (foodstuffs) and durum wheat samples (feed materials).

Aflatoxin	Contamination Level ( $\mu\text{g kg}^{-1}$ )	Recovery $\pm$ SD (%)	Recommended Range (%)
	Foodstuffs (n = 18)		
B <sub>1</sub>	1	76.4 $\pm$ 6.5	70-110
	2	83.0 $\pm$ 9.8	
	3	92.2 $\pm$ 8.3	
B <sub>2</sub>	0.25	79.5 $\pm$ 11.6	50-120
	0.50	82.1 $\pm$ 9.9	
	0.75	92.8 $\pm$ 8.0	
G <sub>1</sub>	1	80.4 $\pm$ 9.6	70-110
	2	83.4 $\pm$ 11.1	
	3	94.6 $\pm$ 8.2	
G <sub>2</sub>	0.25	89.2 $\pm$ 16.9	50-120
	0.50	82.0 $\pm$ 10.7	
	0.75	87.7 $\pm$ 10.1	
	Feed materials (n = 12)		
B <sub>1</sub>	10	75.7 $\pm$ 6.3	N.A. <sup>a</sup>
	20	74.3 $\pm$ 4.7	
	30	72.6 $\pm$ 3.9	

<sup>a</sup> N.A., Not Available; a legal value has not been established.

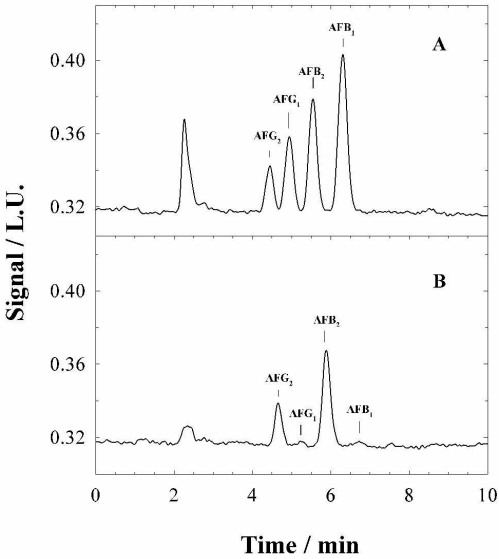


Figure 1

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Figure 1  
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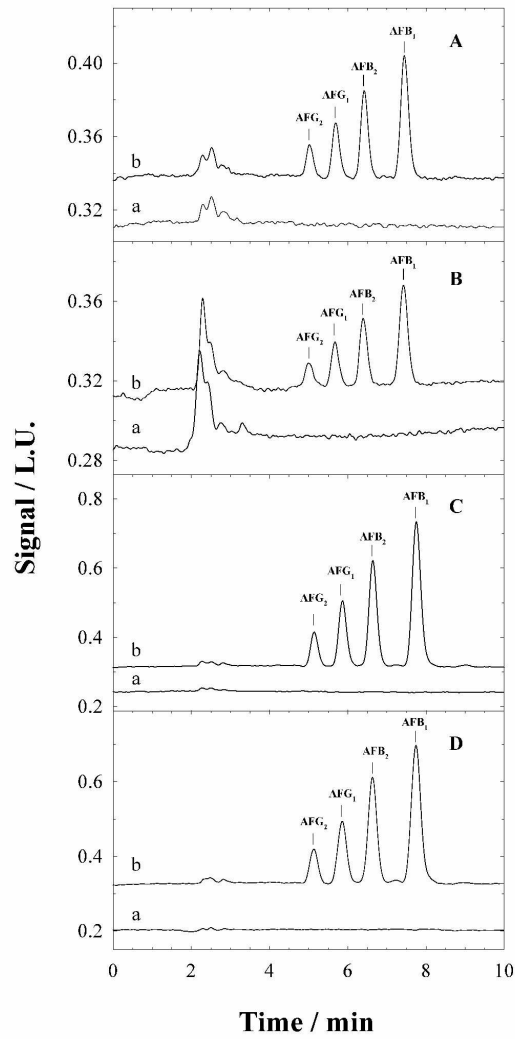


Figure 2

*M. Muscarella et al.*

Figure 2  
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