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TOXIGENICITY OF FUSARIUM SPECIES IN *GIBBERELLA FUJIKUROI* SPECIES COMPLEX (GFSC) ASSOCIATED WITH STALK AND EAR ROT DISEASE OF CORN

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ABSTRACT

Fusarium stalk and ear rot disease did not only cause significant losses of yield but also produced mycotoxins that are harmful to animals and human. This study was conducted to elucidate three major mycotoxins i.e. fumonisin B₁ (FUMB₁), moniliformin (MON), and beauvericin (BEA) produced by the *Fusarium* spp. isolated from corn showing typical stalk and ear rot symptoms in Indonesia, Malaysia and Thailand. Twenty selected strains of *Fusarium* species in *Gibberella fujikuroi* species complex i.e. *F. verticillioides*, *F. proliferatum*, *F. subglutinans*, and *F. konzum* were analyzed for production of the three mycotoxins by using an Ultra Performance Liquid Chromatograph (UPLC). All strains of *F. verticillioides* and *F. proliferatum* produced FUMB₁ at high levels and MON at low levels. Many strains of *F. verticillioides* (67%) and *F. proliferatum* (50%) did not produce BEA while the others produced BEA at low levels. Two strains of *F. subglutinans* did not produce FUMB₁ but produced MON at low levels. One strain of *F. subglutinans* produced BEA and the other one did not produce the toxin. Two strains of *F. konzum* produced both MON and BEA at low levels but only one strain produced FUMB₁ at a low level. These mycotoxins have not been reported from *Fusarium* spp. in *Gibberella fujikuroi* species complex isolated from stalk and ear rot diseases of corn in these areas. Therefore, concerted efforts must be made to educate all stake holders about the presence and health hazards of these mycotoxins.

Keywords: Moniliformin (MON), fumonisin (FUMB₁), beauvericin (BEA).

INTRODUCTION

Many species of *Fusarium* in *Gibberella fujikuroi* species complex (Gfsc) such as *F. verticillioides*, *F. proliferatum*, and *F. subglutinans* have been known as the causal agents of stalk and ear rot diseases on corn in all major corn producers of the world (Reference). In addition, these *Fusarium* species are capable of producing a variety of mycotoxins, such as fumonisins (FUM), moniliformin (MON), and beauvericin (BEA) (Bottalico *et al.*, 1989; Logrieco *et al.*, 1995; Moretti *et al.*, 1997; Chulze *et al.*, 1998; Shephard *et al.*, 1999). The occurrence of mycotoxins in this cereal grain is of great concern worldwide, because their presence in feeds and food is often associated with chronic or acute mycotoxicoses in livestock and, to a lesser extent, also in human (Charmley *et al.*, 1995).

FUM are natural contaminants of cereal grains

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worldwide and are mostly found in corn and products derived from corn (Bullerman, 1996; Visconti, 1996; Weidenbörner *et al.*, 2001), and is produced by a variety of *Fusarium* species mainly those in *Gibberella fujikuroi* species complex such as *F. verticillioides*, *F. proliferatum*, and some other related species e.g. *F. fujikuroi*, *F. konzum*, and *F. nygamai* (formally *F. moniliforme*; teleomorph *Gibberella fujikuroi* species complex) (Gelderblom *et al.*, 1988; Thiel *et al.*, 1991; Nelson *et al.*, 1992). *F. verticillioides* is a pathogen of agriculturally important cereals, especially corn, and it is considered as one of the most important toxigenic fungi worldwide; as the main source of FUM contamination of food and feed products (Nelson *et al.*, 1993; Moss, 1996). The most abundant FUM produced in nature is FUM B₁ (FUMB₁) that caused several chronic and acute diseases in human and animals (Gelderblom *et al.*, 1988; Desjardins, 2006). According to Desjardins (2006), high levels of FUMB₁ have been found consistently in corn infected by strains of *F. verticillioides* and *F. proliferatum*, but FUMB₁

production was discontinuous among the other species of the Gfsc. As stated by Nelson *et al.* (1991), strains of *F. verticillioides* generally produce moderate to high levels of fumonisins (400 - 4000 mg/kg). Results of a study conducted by Acuna *et al.* (2005) showed that almost all strains of *F. verticillioides* (97.1%) and *F. proliferatum* (97.1%) produced FUMB₁ (5.6 - 25846.4 mg/kg) and (6.9 - 3885.0 mg/kg) respectively, while *F. subglutinans* did not produce FUM.

Like FUM, MON also was found widely in food and feeds infected by strains of *Fusarium* species in *Gibberella fujikuroi* species complex such as *F. proliferatum*, *F. subglutinans*, *F. avenaceum*, and *F. tricinctum* (Gutleb *et al.*, 2002; Logrieco *et al.*, 2002). Results of a survey conducted by Desjardins (2006) showed that in the Gfsc, MON production was widespread but not universal. Most notably, many strains of *F. proliferatum*, *F. subglutinans*, and *F. thapsinum* produced high levels of MON, but *F. verticillioides* very rarely produced MON. Individual species do vary widely in the frequency of MON-producing strains and in the levels of MON produced. Also stated by Leslie *et al.* (1995) that *F. verticillioides* produce little or no MON.

Beauvericin (BEA) is a mycotoxin produced by several *Fusarium* species, mainly by *F. proliferatum*, *F. semitectum*, and *F. subglutinans* (Moretti *et al.*, 1997; Logrieco *et al.*, 1998; Shephard *et al.*, 1999). Although most of FUM-producing *Fusarium* species also produced BEA, however, the frequency and levels of BEA differ between individual strains (Desjardins, 2006). *F. verticillioides* and *F. proliferatum* are important corn pathogens causing stalk and ear rot all over the world including Southeast Asia, and can produce a variety of mycotoxins including BEA both in pre-harvested and in stored products (Bottalico *et al.*, 1989; Logrieco *et al.*, 1995; Moretti *et al.*, 1997; Chulze *et al.*, 1998; Shephard *et al.*, 1999). According to Leslie *et al.* (2004), *F. konzumi* produce variable but generally low to moderate amounts of BEA (4 - 320 µg/g). Besides the threats, mycotoxin profiles also are important chemotaxonomic criteria in the identification and characterization of *Fusarium* species. Nelson *et al.* (1993), and Thrane and Hansen (1995) have revealed species-specific metabolite profiles of *Fusarium* species. Also, Fotso *et al.* (2002) found that individual species of *Fusarium* produced different classes and levels of secondary metabolites. For example, gibberellic acid (GA) could be used to differentiate *F. fujikuroi* with several other closely

related species in *Gibberella fujikuroi* species complex (Nur Ain Izzati, 2007). So far, most studies of *Fusarium* mycotoxin profiles were using strains from the temperate region which might be different than those produced by tropical strains.

This study was conducted to elucidate toxigenicity of three most important mycotoxins i.e. FUMB₁, MON, and BEA produced by *Fusarium* species in *Gibberella fujikuroi* species complex isolated from corn showing typical stalk and ear rot symptoms in Indonesia, Malaysia, and Thailand.

MATERIALS AND METHODS

Strains and Chemicals: A total of 20 strains representing four *Fusarium* species i.e. *F. verticillioides* (12 strains), *F. proliferatum* (4 strains), *F. subglutinans* (2 strains), and *F. konzumi* (2 strains) isolated from stalk and ear rot-infected corn plants were used to study the mycotoxin toxigenicity (Table 1). FUMB₁, MON, and BEA standards, sodium borate (Na₂B₄O₇), 2-mercaptoethanol, 2-ME (HOCH₂CH₂SH), tetrabutylammonium hydrogen sulphate (TBAHS), (C₁₆H₃₅NH₂SO₄), and orthophthalaldehyde, OPA were purchased from Sigma-Aldrich, USA. Sodium dihydrogen phosphate monohydrate (NaH₂PO₄), potassium dihydrogen phosphate (KH₂PO₄), potassium chloride (KCl) from Univar, Australia. Orthophosphoric acid (H₃PO₄), acetonitrile, ACN (CH₃CN) HPLC grade, methanol, MeOH (CH₃OH) HPLC grade, n-heptane (C₇H₁₆) HPLC grade and dichloromethane (CH₂Cl₂) were purchased from Fisher Scientific, UK and C18-SPE column from Supelco, USA.

Fusarium Culture Preparation: About 15 g of washed and dried corn grits were placed into 100 ml Erlenmeyer flask, plugged with cotton wool and covered with aluminum foil, and autoclaved for 45 min at 15 psi, 121°C. The sterile corn grits in Erlenmeyer flasks were inoculated with 1 ml conidial suspension (1 x 10⁷ conidia/ml), and then added with 5 ml of sterile distilled water to keep the moisture of corn grits. The Erlenmeyer flask was daily hand-shaken to homogenize the conidial suspension and incubated for 30 days in the dark.

Mycotoxin Extraction, Clean up, and Chemical analysis: All cultured media were extracted, cleaned up, and assayed for the following mycotoxins by using an Ultra Performance Liquid Chromatography (UPLC) as follows.

Fumonisin B₁ (FUMB₁): The method employed for fumonisin extraction was adapted from Nelson *et al.* (1991).

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Table 1. Strains of *Fusarium* species in Section *Liseola* isolated from corn showing typical stalk and ear rot symptoms in Indonesia, Malaysia and Thailand used for mycotoxin toxigenicity analysis.

Strains code	Location	Region	Country	Organ Ear, Stalk	Species name
R1060	Bukit Tamiang	Perlis	Malaysia	Ear	<i>F. verticillioides</i>
P4450	MARDI Bertam	Penang	Malaysia	Ear	<i>F. verticillioides</i>
K24040	Gurun	Kedah	Malaysia	Stalk	<i>F. verticillioides</i>
K24050	Gurun	Kedah	Malaysia	Stalk	<i>F. verticillioides</i>
OLN01880	Bogor	West Java	Indonesia	Ear	<i>F. verticillioides</i>
OLN02000	TulungAgung	East Java	Indonesia	Ear	<i>F. verticillioides</i>
OLN02270	Medan	North Sumatra	Indonesia	Ear	<i>F. verticillioides</i>
OLN02600	Medan	North Sumatra	Indonesia	Stalk	<i>F. verticillioides</i>
OLN02660	Agam	West Sumatra	Indonesia	Ear	<i>F. verticillioides</i>
OLN03440	Padang-Pariaman	West Sumatra	Indonesia	Stalk	<i>F. verticillioides</i>
HLN01550	Tak Fa	Nankhon Sawan	Thailand	Stalk	<i>F. verticillioides</i>
HLN01800	Songkhla	Hat Yai	Thailand	Stalk	<i>F. verticillioides</i>
Q55650	Sri Aman	Sarawak	Malaysia	Ear	<i>F. proliferatum</i>
OLN01870	Bogor	West Java	Indonesia	Ear	<i>F. proliferatum</i>
OLN03810	Banda Aceh	Aceh	Indonesia	Ear	<i>F. proliferatum</i>
HLN01600	Tak	Tak	Thailand	Stalk	<i>F. proliferatum</i>
S48950	Ranau	Sabah	Malaysia	Stalk	<i>F. subglutinans</i>
OLN01860	Bogor	West Sumatra	Indonesia	Ear	<i>F. subglutinans</i>
OLN03430	Padang-Pariaman	West Sumatra	Indonesia	Stalk	<i>F. konzum</i>
OLN04920	Agam	West Sumatra	Indonesia	Stalk	<i>F. konzum</i>

About 10 g of inoculated corn grits were suspended with 50 ml of acetonitrile: water (50:50, v/v), and homogenized in a Waring blender for 5 minutes. The mixture was filtered through a Whatman no. 4 filter paper and separated by using a separatory funnel; the bottom layer was taken and evaporated to near dryness at 65°C by using a rotary evaporator (Buchi 461, Switzerland). The solvent residue was dissolved in 1 ml of methanol.

The filtrate was cleaned up on a C-18 solid phase extraction (SPE) column. The filtrate (1 ml) was added to 2.5 mL of 1% aqueous KCl and was passed through the C-18-SPE column, which had been preconditioned with methanol (5 ml), followed by 5 ml of 1% aqueous KCl. The column was then washed with 3 ml of 1% aqueous KCl, followed by 2 ml of acetonitrile: 1% aqueous KCl (10:90, v/v). The fumonisins were eluted off the C₁₈-SPE column with 2 ml of acetonitrile: water (50:50, v/v) and was ready for the pre-column derivatization.

O-Phthaldialdehyde (OPA) derivatising agent was prepared by adding methanol (1ml) to OPA (40 mg) and diluted with 5 mL 0.1 mol L⁻¹ sodium borate, then

50 µl of 2-ME was added to the mixture. This reagent is stable in the dark for up to 8 days in capped, aluminum foil-covered vials (Abramovic *et al.* 2005). The OPA reagent (200 µl) was added to a sample or standard solution (50 µl) and was mixed well. Five µL of this solution was injected into the UPLC unit, within four minutes after the derivatization. The mobile phase was methanol: mixture (0.1% sodium dehydrogen phosphate with pH 3.35 adjusted with o-phosphoric acid) (78:22). Detection of fumonisin was by fluorescence (FLR) detector with wavelength set at 305 nm for excitation and 432 nm for emission. Calculation of FUMB₁ concentrations of tested samples was based on peak areas of samples compared with those of standards.

Moniliformin (MON): MON extraction was carried out by following the techniques described by Burmeister *et al.* (1979). About 10 g of inoculated corn grits were soaked with 100 ml of 1% tetrabutylammonium hydrogen sulphate (TBAHS) in ddH₂O and taken for 30 minutes. Then the shaken corn grits were filtered through a Whatman no.4 filter paper and defatted with 10 ml of n-hexane in a separating funnel and the bottom layer was taken. Dichloromethane (same volume as

sample) was added to the sample solution and mixed gently. The mixture was separated by using a separatory funnel and the sample solution at bottom layer was taken and evaporated in a Buchi (Switzerland) rotary vacuum evaporator at 55°C. Then, the soluble residue was dissolved in 1 ml dichloromethane, filtered through 0.2 µm Millipore filter, and kept in a bottle at 5°C until used. The filtrate was cleaned up by the C₁₈-SPE column as described for FUMB₁. Mobile phase was acetonitrile and mixture (50 ml of 40% tetrabutylammonium hydrogen sulphate, 100 ml of 1.1 M potassium dehydrogen phosphate, 850 ml ddH₂O, pH 6.5 adjusted by 5N KOH) (8:92). MON was detected by a photodiode array (PDA) detector at wavelength 229 nm.

Beauvericin (BEA): Procedure for beauvericin detection was adapted from Logrieco *et al.* (1998). About 15 g of corn grits were soaked overnight with 75 ml of acetonitrile: methanol: water (16:3:1; v/v), and milled in a Waring blender for five minutes. The milled corn grits were filtered through a Whatman no. 4 filter paper, and then defatted twice with 25 ml of n-hexane in a separating funnel. The bottom layer was evaporated to near dryness at 80°C by using a vacuum rotary evaporator (Buchi 461, Switzerland). The solvent residue was dissolved in 50 ml of methanol: water (1:1 v/v) and extracted twice with 25 ml of dichloromethane. Then, the solution was evaporated and redissolved in 1 ml of methanol, filtered through 0.2 µm Millipore filter, and kept in 5 ml Bijoux bottle at 5°C condition until used. The filtrate was cleaned up by the C₁₈-SPE column as described for FUMB₁. Mobile phase used for BEA detection was methanol: water (85:15; v/v) with flow rate a 0.5 ml/min. BEA was detected by a photodiode array (PDA) detector at wavelength 205 nm.

RESULTS AND DISCUSSION

The results of this study showed that each strain of *Fusarium* species has a different ability to produce the three mycotoxins, FUMB₁, MON, and BEA. Representative production of FUMB₁, MON, and BEA by each strain were indicated in Figure 1. Concentrations of three mycotoxins produced by *Fusarium* species were shown in Table 2. FUMB₁ were produced in high concentrations up to 32756.3 µg/g mainly by strains of *F. verticillioides* and *F. proliferatum*, although there were some strains that produced FUMB₁ with rather low concentrations. In general, the productions of FUMB₁ by *F. verticillioides* were higher than those by *F. proliferatum*. These two fungi were known as the major

FUM-producing species (Gelderblom *et al.*, 1988; Thiel *et al.*, 1991; Nelson *et al.*, 1992). Also, the two species of *Fusarium* always produce FUM in high levels, while others in Gfsc do not always produce FUM as stated by Desjardins (2006). On the contrary, two strains of *F. subglutinans* tested did not produce the FUMB₁. As mentioned by Nelson *et al.* (1992) and Leslie *et al.* (2004) that *F. subglutinans* produced little or no FUMB₁. The results of this study were similar with those by Acuna *et al.* (2005) in which almost all strains of *F. verticillioides* and *F. proliferatum* produced FUMB₁ at the levels ranging from 5.6 to 25846.4 mg/kg and from 6.9 to 3885.0 mg/kg respectively, while *F. subglutinans* did not produce FUMB₁. In the presence study, one strain of *F. konza* produce FUMB₁ at low level, and the other strain did not produce the toxin. This is in accordance with that proposed by Leslie *et al.* (2004) that *G. konza* (teleomorph of *F. konza*) strains produced little or no fumonisins (up to 120 µg/g by one strain).

Moniliformin (MON) derived from *F. moniliforme*, the fungal species that was identified as the original toxin producer in the United State in 1993 (Cole *et al.*, 1973; Marasas *et al.*, 1984). However, after re-investigation of MON producing strains indicated that some strains were misidentified as *F. proliferatum* and the others were *F. nygamai* (Marasas *et al.*, 1988). Subsequent studies have confirmed that MON rarely produced by *F. moniliforme* and the amount of MON is not more than trace levels (now renamed as *F. verticillioides*) (Nelson *et al.* 1993; Leslie *et al.* 1996). Rabie *et al.* (1982) stated that the species now recognized as *F. verticillioides* does not generally produce significant levels of MON even though some strains may produce the mycotoxin when grown on corn. However, in this study all strains of *F. verticillioides* produced MON at low levels. The results of this study are not unexpected because *F. verticillioides* has been found to produce MON even though in a very small amount (Leslie *et al.*, 1995) and interestingly, results of a research conducted by Moretti *et al.* (2004) indicated that all strains from banana fruits identified morphologically as *F. verticillioides* and biologically as MP-A produced MON while none of the strains produced FUM and the *F. verticillioides* strains from corn produced FUMB₁ (20 – 5645 µg/g) but did not produce MON. Based on these results, it can be concluded that there are strains of *F. verticillioides* that can produce MON at relatively high levels. Therefore, the results of the study by Moretti *et al.* (2004) can corroborate the results of our

findings. MON formation by strains of *F. proliferatum* and *F. subglutinans* in the present study was also in accordance with the results of several researchers such as Marasas *et al.* (1984), Abbas *et al.* (1989), Chelkowski *et al.* (1990), Leslie *et al.* (1996), and Desjardins *et al.* (1997). Two strains of *F. konzum* produced MON at low levels and there has been no previous report of MON production by *F. konzum*.

BEA production is widely distributed in *Fusarium* species including both FUM-producing and trichothecene-producing species (Bottalico *et al.*, 1995; Shephard *et al.*, 1999; Desjardins *et al.*, 2000; Fotso *et al.*, 2002; Logrieco *et al.*, 2002, and Leslie *et al.*, 2004). In the present study, eight strains of *F. verticillioides* did not produce BEA while the other four strains produced BEA at the low levels (0.6-2.8 µg/g). These results are in

agreement with those reported by Desjardins (2006), that *F. verticillioides* produced little or no BEA. Two of the four tested strains of *F. proliferatum* and one of two tested strains of *F. subglutinans* produced BEA at low levels.

The productions of BEA by the strains of the two species are in accordance with the results of studies that have been published by many researchers such as Krska *et al.* (1996), Moretti *et al.* (1997), Logrieco *et al.* (1998), and Shephard *et al.* (1999). In this study the amounts of BEA produced by *F. proliferatum* and *F. subglutinans* were very low when compared with the results of the research that have been reported by all researchers mentioned above. According to Desjardins (2006) individual species do vary widely in frequency of BEA-producing strains and in the level of BEA produced.

Table 2. Toxigenicity of strains of *Fusarium* spp. in *Gibberella fujikuroi* species complex isolated from corn showing typical stalk and ear rot symptoms in Indonesia, Malaysia and Thailand.

<i>Fusarium</i> species	Strains	Concentration (µg/g)		
		FUMB ₁	MON	BEA
<i>F. verticillioides</i>	R1060	15996.7	1.4	ND
	P4450	25367.1	1.9	0.8
	K24040	20624.7	1.9	ND
	K24050	4550.4	1.7	ND
	OLN01880	12606.3	1.8	ND
	OLN02000	29471.4	2.6	2.8
	OLN02270	16329.6	2.5	2.7
	OLN02600	32756.3	0.7	ND
	OLN02660	9926.8	3.2	ND
	OLN03440	715.6	4.9	ND
<i>F. proliferatum</i>	HLN01550	843.5	1.4	ND
	HLN01800	27692.9	1.9	0.6
	Q55650	156.2	1.7	ND
	OLN01870	13217.6	2.3	3.2
	OLN03810	8933.1	1.2	ND
<i>F. subglutinans</i>	HLN01610	21423.1	3.0	0.1
	S48950	ND	1.6	3.9
	OLN01860	ND	1.1	ND
<i>F. konzum</i>	OLN03430	30.1	2.1	1.2
	OLN04920	ND	0.9	1.0

FUMB₁= Fumonisin B₁; MON= Moniliformin; BEA= Beauvericin; ND= Not Detected.

In conclusion, all strains of *F. verticillioides* and *F. proliferatum* produced FUMB₁ at high levels ranging from 715.6 to 32756.3 µg/g and 156.2 to 21423.1 µg/g, respectively while produced MON at low levels from 0.7 to 4.9 µg/g and 1.2 to 3.0 µg/g, respectively. In general, production of FUMB₁ by strains of *F. proliferatum* was relatively low compared to *F. verticillioides*. Many strains of *F. verticillioides* (67%) and *F. proliferatum* (50%) did

not produce BEA while the others produced BEA at low levels, up to 2.8 and 3.2 µg/g, respectively. Two strains of *F. subglutinans* tested did not produce FUMB₁ but produced MON at low levels, 1.1 and 1.6 µg/g.

One strain of *F. subglutinans* produced BEA (3.9 µg/g) and the other one did not produce the toxin. Two strains of *F. konzum* produced both MON and BEA at low levels but only one strain produced FUMB₁ at a low level.

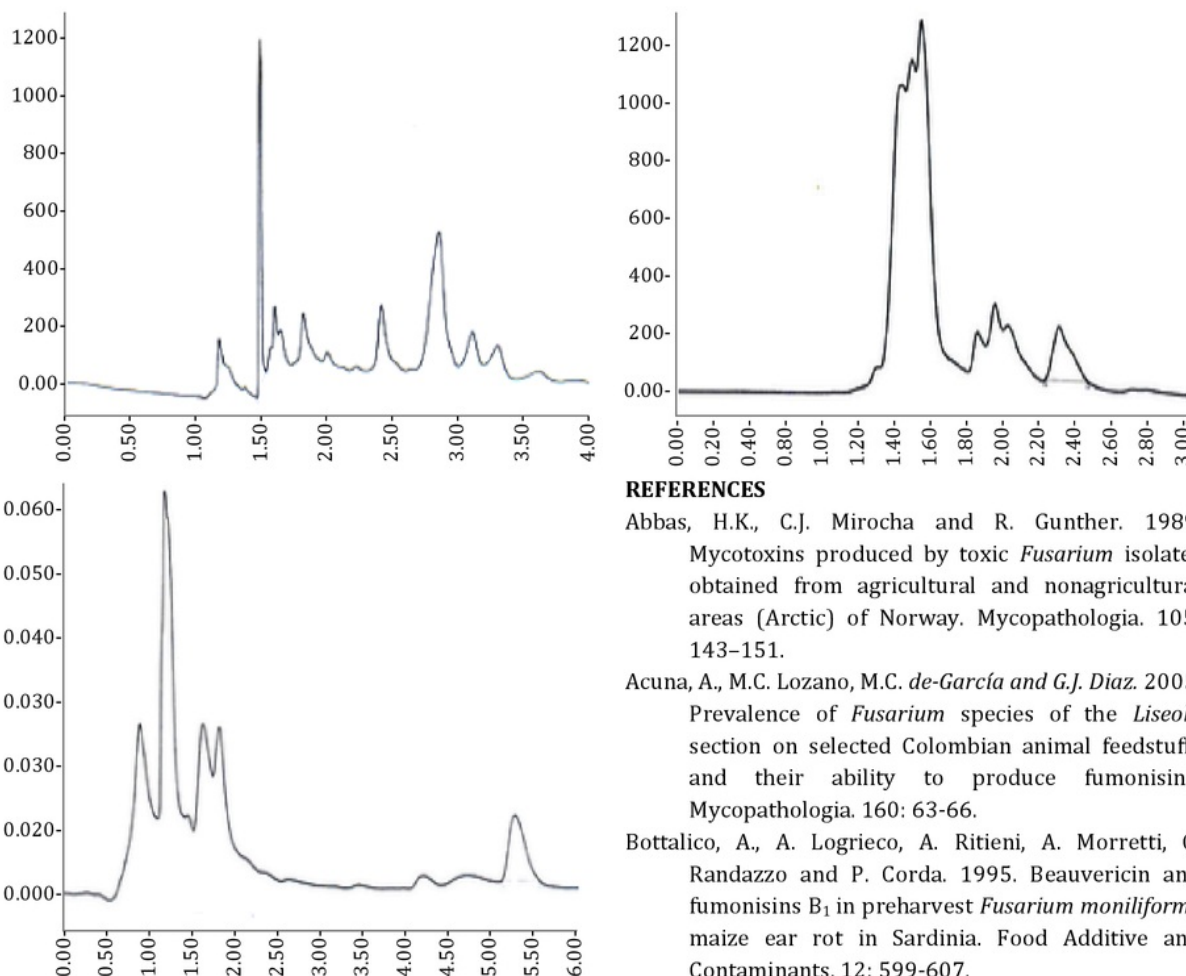


Figure 1. UPLC chromatogram of FUMB₁, 843.3 µg/g (A), MON, 4.9 µg/g (B), and BEA, 2.8 µg/g (C) obtained from corn grits inoculated with *F. verticillioides*, (HLN0155), (OLN03440) and (OLN02000) respectively.

These profiles of mycotoxins have not been reported from *Fusarium* spp. in *Gibberella fujikuroi* species complex isolated from stalk and ear rot diseases in Indonesia, Malaysia, and Thailand. Therefore, concerted efforts must be made to educate all stakeholders, especially corn farmers and those involved in poultry and animal farming, about the presence and health hazards of these mycotoxins.

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