

A Systematic Literature Review on the Effects of Mycotoxin Exposure on Insects, and on Mycotoxin Accumulation and Biotransformation

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Supplementary Table S1: Overview of covered studies including: insect species, substrate used, exposure time of the insects, analytical method used, and mycotoxins (metabolites) analyzed

Reference	Orders	Species	Substrates	Insect stage	Time of exposure	Method of measurement	Mycotoxins Analyzed ¹	Mycotoxin concentrations in feed	Fungus present
Abado-Becognee et al. (1998)	Coleoptera	<i>Tenebrio molitor</i>	Maize flour with 4% (w/w) mineral salt and 13% vitamin B complex	Larvae (7 weeks)	63 days	HPLC w Fluorescence Detector	FB ₁	FB ₁ : 50,000, 150,000, 450,000 µg/kg	No
Bily et al. (2004)	Lepidoptera	<i>Helicoverpa zea</i> and <i>Ostrinia nubilalis</i>	<i>Hel. zea</i> : soybean flour/wheat germ artificial diet.	Larvae (3rd instar)	4, 7, 11 and 14 days	LC-MS w-APCI-mass detector	ZEN	ZEN: 5,000 µg/kg	No

			<i>O. nubilalis</i> : Meredic diet						
Bosch et al. (2017)	Coleoptera, Diptera	<i>Tenebrio molitor</i> and <i>Hermetia illucens</i>	Poultry feed	Larvae (1st instar)	<i>T. molitor</i> : 40 days; <i>H. illucens</i> : 10 days	HPLC w Fluorescence Detector	AFB ₁ , AFM ₁	AFB ₁ : 10, 25, 50, 100, 250 and 500 ug/kg	No
Camenzuli et al. (2018)	Coleoptera, Diptera	<i>Alphitobius diaperinus</i> and <i>Hermetia illucens</i>	<i>A. diaperinus</i> : wheat based with apple; <i>H. illucens</i> : wheat based and water	Larvae (<i>A. diaperinus</i> : 2 weeks and <i>H. illucens</i> : 1 week)	<i>A. diaperinus</i> : 14 days; <i>H. illucens</i> : 10 days	LC-MS/MS	AFB ₁ , AFL, AFM ₁ , AFP ₁ , AFQ ₁ ; DON, 3- AcDON, 15- AcDON, DON- 3G; ZEN, α- ZEN, β-ZEN and OTA	AFB ₁ : 8, 70 and 390 µg/kg; DON: 3,900, 38,000 and 112,000 µg/kg; ZEN: 280, 2,500 and 13,000 µg/kg; OTA: 170, 1,700 and 1,300 µg/kg. Mixtures: AFB ₁ : 18, 180 and 430 µg/kg; DON: 4,100, 41,000 and 100,000 µg/kg ; ZEN: 400, 3,800 and 9,400 µg/kg; OTA: 80, 800 and 2,000 µg/kg	No
Cao et al. (2019)	Diptera	<i>Drosophila simulans</i>	Grapes	Eggs-adult	Until adult	RT-PCR/HRM Not mentioned	OTA	OTA: 0.05, 0.5 µg/kg	Yes
Chinnici et al. (1979)	Diptera	<i>Drosophila melanogaster</i> (strains A-9 and A-11)	Control media and media containing AFB ₁ (prepared according to Chinnici et al. 1976)	Larvae (1-5 days)	Until adult	Thin layer chromatography	AFB ₁	AFB ₁ : 440 and 880 µg/kg	No

Cito et al. (2016)	Coleoptera	<i>Tenebrio molitor</i>	Bread and bran	Larvae (mature)	20 days	LC-UV-MS	Beauvericin A, bassianolide and beauverolides	Not specified	<i>Beauveria bassiana</i> (strains: B 13/I03, B 13/I11, B 13/I49, B 13/I57, B 13/I63, and B 13/I64)
Davis & Schiefer (1982)	Coleoptera	<i>Tenebrio molitor</i>	Whole wheat supplemented with brewer's yeast (9:1)	Larvae (8.5-11.5 mg)	4 weeks	Micro-Kjeldahl technique and Technicon Autoanalyzer Calculations from known concentration	T-2	T-2: 2,000, 4,000, 8,000, 16,000, 32,000, 64,000 and 128,000 µg/kg	No
De Zutter et al. (2016)	Hemiptera, Homoptera	<i>Sitobion avenae</i> , <i>Acyrtosiphon pisum</i>	Wheat seedlings and young broad bean plants	Nymphs	3 days	LC-MS/MS	DON, DON-3G, 3- and 15- AcDON	DON: 500, 1,000, 3,000 µg/kg; DON-3G: 500, 1,000, 3,000 µg/kg	No
Dowd (1989)	Lepidoptera	<i>Heliothis zea</i>	Pinto bean-based diet + three allelochemicals (gossypol, a saponin, and 6-methoxy2- benzoxazolinone)	Larvae (neonate)	7 days	Observations (mortality, weight) Calculations from known concentration	Fusaric acid	Fusaric acid: 25,000 and 250,000 µg/kg	No

Dowd (1990)	Lepidoptera	<i>Heliothis zea</i> , <i>Spodoptera frugiperda</i>	Pinto bean	Larvae (last instar)	48 hours	Enzyme assays (midgut) Thin layer chromatography	DON, T-2, diacetoxyscirpe nol	DON: 2,500, 25,000, 250,000 µg/kg; T-2: 2,500, 25,000 µg/kg; diacetoxyscirpenol: 2,500, 25,000 µg/kg	No
Dowd (1993)	Lepidoptera	<i>Helicoverpa zea</i> , <i>Spodoptera frugiperda</i>	Pinto bean	Larvae (1st and 3rd instar)	7 days	HPLC	Griseofulvin	Griseofulvin: 25,000 µg/kg	No
Dowd et al. (1988)	Lepidoptera	<i>Heliothis zea</i> , <i>Spodoptera frugiperda</i>	Pinto bean	Larvae (neonate)	7 days	Observations (mortality, weight) Not mentioned	Dihydroxyaflavine, roseotoxin B, penitrem A, verruculogen, cytochalasin H, paspaline, paxilline	Up to 25,000 µg/kg ww (100,000 µg/kg dw) of dihydroxyaflavinine, roseotoxin B, penitrem A, verruculogen, cytochalasin H, paspaline or paxilline	No
Elzaki et al. (2019)	Lepidoptera	<i>Helicoverpa armigera</i>	Artificial diet + and - MeJA (prepared according to Qi et al. 2000)	Larvae (2nd instar)	Until pupation	qRT-PCR Not mentioned	AFB ₁	AFB ₁ : 1,000 µg/kg	No
Gulsunoglu et al. (2019)	Diptera	<i>Hermetia illucens</i>	SSF kernels	Larvae (2nd instar)	12 days	LC– MS/MS, Observations (mortality, weight), Gravimetric method, Micro-Kjeldahl, Goldfish method	DON	DON: 630-3,580 µg/kg	Fusarium spp.

Gunst et al. (1982)	Diptera	<i>Drosophila melanogaster</i> (strains Florida-9 and Lausanne-S)	Five types: control, media + AFB ₁ , media + AFB ₁ , media + AFG ₁ and media + ST (prepared according to Chinnici et al., 1976)	Egg-adult	Whole life-cycle	Thin layer chromatography	AFB ₁ , AFB ₂ , AFG ₁ ; sterigmatocystin	AFB ₁ , AFB ₂ , AFG ₁ ; sterigmatocystin: 200, 600, 2,000 and 4,000 µg/kg	No
Hegde et al. (1967)	Lepidoptera	<i>Corcyra cephalonica</i>	Wheat bran, groundnut meal	Larvae (10 days)	20 days	Observations (mortality, weight, growth), Paper chromatography	AFB ₁ , AFG ₁	AFB ₁ : 1,000,000 µg/kg	<i>Aspergillus flavus</i> , <i>Aspergillus oryzae</i> , <i>Penicillium purpurogenus</i> and <i>Penicillium rubrum</i>
Jankovic-Tomanic et al. (2019)	Coleoptera	<i>Tenebrio molitor</i>	Wheat bran artificially contaminated	Larvae (2 months)	2 weeks	<u>Spectrophotometry</u> <u>Calculations from known concentration</u>	DON	DON: 4,900, 8,000, 16,000 and 25,000 µg/kg	No
Johnson et al. (2012)	Hymenoptera	<i>Apis mellifera</i>	Bee candy (2 sucrose:1 water)	Newly emerged bees	3 days	<u>Longevity assay</u> , <u>RNA extraction</u> , <u>Blot analysis</u> , <u>Gut dissection</u> <u>Calculations from known concentration</u>	AFB ₁	AFB ₁ : 20,000 µg/kg	No
Kanaoka et al. (1978)	Lepidoptera	<i>Bombyx mori</i>	Artificial diet	Larvae (3rd instar)	8 days	<u>PMR spectra</u> , <u>Observations</u>	Beauvericin, bassianolide	Beauvericin: 4,000, 8,000, 1,000,000 µg/kg;	<i>Beauveria bassiana</i> ,

						(mortality, weight)Silica gel column chromatography		bassianolide: 1,000, 2,000, 4,000, 8,000, 12,000 or 16,000 µg/kg	<i>Verticillium lecanii</i>
Kirk et al. (1971)	Diptera	<i>Drosophila melanogaster</i> (strain Oregon R)	Yeast-corn meal molasses growth medium	Larvae (1st instar)	24 days	Observations (development) Not mentioned	AFB ₁	AFB ₁ : 10,000 µg/kg	No
Lee & Campbell (2000)	Lepidoptera	<i>Amyelois transitella</i> , <i>Cydia pomonella</i>	<i>Am. transitella</i> : walnuts; <i>C. pomonella</i> : apples	Larvae (1st instar)	Not applicable	HPLC w Fluorescence Detector	AFB ₁ , AFB ₂ , AFB _{2a} , AFL, AFM ₁ , AFM ₂ , AFG ₁ , AFG ₂ , AFB ₁ -8,9-epoxide and AFB ₁ -8,9-epoxide-GSH conjugate	AFB ₁ : 3,123,000 µg/kg	No
Leni et al. (2019)	Coleoptera, Diptera	<i>Alphitobius diaperinus</i> , <i>Hermetia illucens</i>	Naturally contaminated by-products of corn, wheat, rice, rapeseed, apple, olive and carrots	Larvae (2 days)	<i>A. diaperinus</i> : 28 days; <i>H. illucens</i> : 15 days	HPLC w Fluorescence Detector, UHPLC-MS/MS	DON, 3-AcDON, fusarenone X, diacetoxyscirpenol, T-2, HT-2, FB ₁ , FB ₂ , ZEN, AFB ₁ , patulin, OTA, nivalenol	DON: 416, 468, 557, 608, 726, 755 µg/kg; FB ₁ : 127 µg/kg; FB ₂ : <LOD; ZEN: <LOD	No

Llewellyn et al. (1988)	Hemiptera	<i>Oncopeltus fasciatus</i>	Water, unsalted raw sunflower seeds	Larvae (5th instar)	21 days	Observations (mortality, weight)Calculations from known concentration	AFB ₁	AFB ₁ : 5,000 µg/kg	No
Llewellyn et al. (1976)	Blattodea	<i>Paradelphomyia americana</i>	Sucrose water	Adult (males)	56 days	Observations (weight)Not mentioned	AFB ₁	AFB ₁ : 12,000 µg/kg	No
Matsumura & Knight (1967)	Diptera	<i>Aedes aegypti</i> , <i>Drosophila melanogaster</i> and <i>Musca domestica</i>	<i>Ae. aegypti</i> : distilled water; <i>D. melanogaster</i> : standard food medium; <i>M. domestica</i> : sucrose solution and milk (1:1)	<i>Ae. aegypti</i> : larvae (4th instar) and adults; <i>D. melanogaster</i> : adults; <i>M. domestica</i> : adults	5 days	Observations (mortality)Not mentioned	AFB ₁	AFB ₁ : <i>Ae. aegypti</i> larvae 3,000 µg/kg (unclear for <i>Ae. aegypti</i> adults, <i>D. melanogaster</i> and <i>M. domestica</i>)	No
Meijer et al. (2019)	Diptera	<i>Hermetia illucens</i>	Wheat based mashed feed	Larvae (1st instar)	9 days	LC-MS, S9-Fractions, Observations (mortality, weight)	AFB ₁	AFB ₁ : 500 µg/kg	No
Melone & Chinnici (1986)	Diptera	<i>Drosophila melanogaster</i> (strains Oregon-R and Lausanne-S)	Fly culture medium (dextrose, yeast, agar, inorganic salts, and methyl p-hydroxybenzoate)	Egg-adult	Whole life- cycle, multiple generations	Observations (mortality)Calculation s from known concentration	AFB ₁	AFB ₁ : 500, 1,000, 1,300, 1,600, 1,900, 2,200 and 2,500 µg/kg	No

Mencarelli et al. (2013)	Lepidoptera	<i>Ostrinia nubilalis</i>	Corn	Larvae (4th instar)	14 days	Observations (mortality) <u>Not mentioned</u>	AFB ₁	AFB ₁ : 125-30,000 µg/kg	<i>Aspergillus flavus</i>
Miller et al. (2008)	Lepidoptera	<i>Choristoneura fumiferana</i>	Spruce Trees	Larvae (2nd instar)	3 months (until 6th instar)	Observations (weight) <u>Not mentioned</u>	Rugulosin	Rugulosin: 850 µg/kg (geometric mean)	No
Nevins & Grant (1971)	Diptera	<i>Musca domestica</i>	Moistened dog food pellets	Larvae (2nd instar)	7 days	Thin layer chromatography	AFB ₁	AFB ₁ : 20 µg/kg	<i>Aspergillus flavusoryzae</i>
Niermans et al. (2019)	Coleoptera	<i>Tenebrio molitor</i>	Wheat flour	Larvae (42 days)	4 or 8 weeks	HPLC-MS/MS, Observations (mortality, weight)	DON, ZEN, β-ZEL	DON: spiked with 568 and 576 µg/kg, artificially contaminated with 939 and 2,101 µg/kg and naturally contaminated with 2,854 and 4,588 µg/kg. ZEN: spiked with 589 and 2,254 µg/kg, artificially contaminated with 427 and 2,283 µg/kg and naturally contaminated with 602 and 919 µg/kg	No
Niu et al. (2011)	Hymenoptera	<i>Apis mellifera</i>	Bee candy (2 sucrose:1 water)	Workers	3 days	Bioassays (mortality) <u>Calculation s from known concentration</u>	AFB ₁ , OTA	AFB ₁ : 500, 1,000, 2,000, 5,000, 7,000, 10,000, 15,000, 20,000 µg/kg.	No

								OTA: 1,000, 5,000, 10,000, 20,000, 40,000, 60,000 µg/kg	
Niu et al. (2009)	Lepidoptera	<i>Amyelois transitella</i> and <i>Helicoverpa zea</i>	Not specified	Larvae (1st and 5th instar)	Until pupation	HPLC-w-photodiode array-UV-detector	AFB ₁ , OTA	AFB ₁ : 1,000, 5,000, 10,000, 20,000, 50,000 and 100,000 µg/kg. OTA: 1,000, 5,000, 10,000, 20,000 and 50,000 µg/kg	No
Niu et al. (2008)	Lepidoptera	<i>Helicoverpa zea</i>	Artificial diet	Larvae (5th instar)	48 hours	HPLC-w-UV-detector, LC-MS, RT-PCR	AFB ₁	AFB ₁ : 1,000 µg/kg	No
Ochoa Sanabria et al. (2019)	Coleoptera	<i>Tenebrio molitor</i>	Wheat (naturally contaminated)	Larvae (7th-9th instar)	Until pupation	HPLC-MS	DON, 3-AcDON	DON: 2,000, 10,000, 12,000 µg/kg. 3-AcDON 52, 63, 205 µg/kg	No
Ohtomo et al. (1975)	Lepidoptera	<i>Bombyx mori</i>	Not specified	Larvae (5th instar)	5 days	Observations (mortality); Thin layer chromatographyLC, ultra-violet and infrared analysis	AFB ₁	AFB ₁ : 15,614 µg/kg	<i>Aspergillus flavus</i> (K-199)
Patterson et al. (1987)	Diptera, Lepidoptera	<i>Drosophila melanogaster</i> , <i>Spodoptera littoralis</i>	<i>D. melanogaster</i> : maize; <i>S.littoralis</i> : beans	Larvae (<i>D. melanogaster</i> : 2nd instar and <i>S. littoralis</i> : 4th instar)	3 days	Observations (mortality)Thin layer chromatography	OTA, brevianamide, A, citrinin, penicillic acid, viomellein,	10,000 µg/kg for all	<i>Penicillium</i>

							patulin, cyclophenol		
Patterson et al. (1990)	Lepidoptera	<i>Spodoptera frugiperda</i> and <i>Heliothis virescens</i>	Bean based diet	Larvae (3rd-6th instar)	3 days	Observations (mortality, weight) <u>Preparative layer chromatography</u>	Brevianamide A and D, OTA	Brenianamide A and B, OTA: 1,000 and 10,000 µg/kg	<i>Penicillium vinidicatum</i>
Piacenza et al. (2020)	Coleoptera	<i>Tenebrio molitor</i>	Oat flakes	larvae (42 days)	4 weeks	HPLC-MS/MS, Observations (mortality, weight)	T-2 and HT-2	Sum of T-2 and HT-2 (approx. 100 and 250 µg/kg)	No
Purschke et al. (2017)	Diptera	<i>Hermetia illucens</i>	Substrates based on corn semolina + contaminated corn grains (DON and ZEN)	Larvae (7 days)	13 days	HPLC-MS/MS QTRAP	AFB ₁ , AFB ₂ , AFG ₂ , OTA, DON, ZEN	DON: naturally contaminated with 4600 µg/kg, AFB ₁ : 88 µg/kg, AFB ₂ : 17 µg/kg, AFG ₂ : 46 µg/kg, OTA: 260 µg/kg ZEN: naturally contaminated with 860 µg/kg	No
Rizwan-UL- Haq et al. (2009)	Lepidoptera	<i>Spodoptera exigua</i>	Semi-synthetic diet	Larvae (neonate)	8 days	Observations (mortality, weight) <u>HPLC</u>	Destruxin B	Destruxin B: 15,000, 30,000, 45,000, 60,000, 75,000, 90,000 µg/kg	<i>Metarhizium anisoplae</i>
Sadek (1996)	Lepidoptera	<i>Spodoptera littoralis</i>	Artificial diet	Larvae (2nd instar)	Whole life- cycle	Observations (mortality, development) <u>Not mentioned</u>	AFB ₁ , AFB ₂ , AFG ₁	AFB ₁ : 500, 1,000, 2,000, 2,500, 3,000 and 3,500 µg/kg, AFB ₂ : 2,000, 3,000 and 4,000 µg/kg,	No

								AFG ₁ : 1,000, 2,000, 3,000 and 4,000 µg/kg	
Saner et al. (1996)	Diptera	<i>Drosophila melanogaster</i> (strain Oregon R(R))	Not specified	-	Not applicable	Northern-blot analysis Not mentioned	AFB ₁	Not specified	No
Şişman et al. (2006)	Diptera	<i>Drosophila melanogaster</i> (strain Oregon-R)	Yeast-agar-sugar medium	Eggs, Larvae, Pupae	37-58 days	Observations (development) Not mentioned	AFB ₁	AFB ₁ : 200, 500, 800 µg/kg	No
Sree & Padmaja (2008)	Lepidoptera	<i>Spodoptera litura</i>	Artificial diet	Larvae (9 days)	1, 24, 48 hours	Observations (mortality, weight) HPLC	Destruxin	Destruxin: 88-693 µg/kg	<i>Metarhizium anisopliae</i> (M-10) & (M-19)
Sumarah et al. (2008)	Lepidoptera	<i>Choristoneura fumiferana</i> , <i>Lambdina fiscellaria</i> , and <i>Zeiraphera canadensis</i>	<i>Picea glauca</i> seedlings	Larvae (2nd and 3rd instar)	7 days	Observations (weight) LC-MS	Rugulosin	Rugulosin: 2,713-81,375 µg/kg	<i>Aspergillus fumigatus</i>
Van Broekhoven et al. (2014)	Coleoptera	<i>Tenebrio molitor</i> , <i>Zophobas atratus</i> , and <i>Alphitobius diaperinus</i>	Maize, beer yeast, bread remains, pent grains, potato steam peelings, cookie remains	Larvae (neonate)	<i>T. molitor</i> : 26 days; <i>Z. atratus</i> : 33 days; <i>A. diaperinus</i> : 21 days	LC-MS	T-2, ZEN, OTA	T-2, ZEN, OTA: 500 µg/kg	No

Van Broekhoven et al. (2017)	Coleoptera	<i>Tenebrio molitor</i>	Wheat flour (spiked and naturally contaminated)	Larvae (5 weeks)	14 days	LC-MS	DON	DON: naturally contaminated with 4,900 µg/kg, spiked with: 8,000 µg/kg	No
Wright et al. (1976)	Coleoptera	<i>Tribolium confusum</i>	Whole wheat flour plus 5% brewer's yeast	Larvae	60 days	Observations (mortality, weight, fecundity)Not mentioned	T-2	T-2: 10,000, 100,000 µg/kg	No
Zeng et al. (2006)	Lepidoptera	<i>Helicoverpa zea</i>	Semi-synthetic diet containing wheat germ	Larvae (1st, 3rd and 5th instars)	13 days	Bioassays (mortality, growth)Calculations from known concentration	AFB ₁	AFB ₁ : 1, 20, 200, 1,000, 20,000 µg/kg	No
Zeng et al. (2013)	Lepidoptera	<i>Trichoplusia ni</i>	Semi-synthetic diet containing wheat germ	Larvae (1, 5, 7, 10 days)	6-16 days	Bioassays (mortality, growth)Calculations from known concentration	AFB ₁	AFB ₁ : 1, 20, 200, 1,000, 3,000, 5,000 µg/kg	No
Zeng et al. (2009)	Lepidoptera	<i>Helicoverpa zea</i>	Semi-synthetic diet containing wheat germ	Larvae (4th and 5th instar)	12 days	Bioassays, RT-PCR, Transcript analysisCalculations from known concentration	AFB ₁	AFB ₁ : 1,000 µg/kg	No
Zhao et al. (2018)	Coleoptera	<i>Ahasverus advena</i>	Wheat flour, rolled oats and yeast (5:5:1 by weight)	Larvae (1, 5, 10 days old)	4-14 days	Observations (mortality, growth)Calculations	AFB ₁	AFB ₁ : 0, 500,000, 1,000,000, 2,000,000, 4,000,000, 8,000,000, and 16,000,000 µg/kg	No

						<u>from known</u> <u>concentration</u>			
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