Edible insects: Appendices

Table A

Microbial levels for different unprocessed edible insects (* potential EU food, †potential EU feed, ‡ potential pet food refer to EFSA, 2013?) measured the harvest stage (larval or adult).

Insect species	Hazard	Load (log cfu/g)	Reference
Tenebrio molitor‡	Total aerobic count	8.6	Caparros Megido et al., 2017
Tenebrio molitor‡	Yeast and mould count	4.7	Caparros Megido et al., 2017
Tenebrio molitor‡ (non-starved)	Total aerobic count	6.4-7.8	Mancini et al., 2019a
Tenebrio molitor‡ (non-starved)	*Enterobacteriaceae*	5.8-6.4	Mancini et al., 2019a
Tenebrio molitor‡ (non-starved)	*Staphylococci*	3.8-5.9	Mancini et al., 2019a
Tenebrio molitor‡ (non-starved)	Lactic acid bacteria	5.2-6.2	Mancini et al., 2019a
Tenebrio molitor‡ (non-starved)	Bacterial endospores	0.0-5.3	Mancini et al., 2019a
Tenebrio molitor‡ (starved)	Total aerobic count	6.4-7.6	Mancini et al., 2019a
Tenebrio molitor‡ (starved)	*Enterobacteriaceae*	4.9-6.4	Mancini et al., 2019a

Insect species	Hazard	Load (log cfu/g)	Reference
Tenebrio molitor‡ (starved)	*Staphylococci*	3.9-4.9	Mancini et al., 2019a
Tenebrio molitor‡ (starved)	Lactic acid bacteria	4.9-6.1	Mancini et al., 2019a
Tenebrio molitor‡ (starved)	Bacterial endospores	0.0-3.6	Mancini et al., 2019a
Tenebrio molitor‡	*Enterobacteriaceae*	6.1-7.1	Osimani et al., 2018a
Tenebrio molitor‡	Lactic acid bacteria	7.7-8.2	Osimani et al., 2018a
Tenebrio molitor‡	Mesophilic aerobes	8.2-8.5	Osimani et al., 2018a
Tenebrio molitor‡	Spore-forming bacteria	3.6-3.7	Osimani et al., 2018a
Tenebrio molitor‡	Total aerobic count	7.7-8.3	Stoops et al., 2016
Tenebrio molitor‡	*Enterobacteriaceae*	6.8-7.6	Stoops et al., 2016
Tenebrio molitor‡	Lactic acid bacteria	7.0-7.6	Stoops et al., 2016
Tenebrio molitor‡	Bacterial endospores	<1.0-3.5	Stoops et al., 2016
Tenebrio molitor‡	Yeast and mould count	5.2-5.7	Stoops et al., 2016
Tenebrio molitor‡	Total aerobic count	8.0-9.3	Vandeweyer et al,. 2017a
Tenebrio molitor‡	*Enterobacteriaceae*	6.8-8.3	Vandeweyer et al,. 2017a

Insect species	Hazard	Load (log cfu/g)	Reference
Tenebrio molitor‡*	Lactic acid bacteria	7.3-8.2	Vandeweyer et al,. 2017a
Tenebrio molitor‡*	Aerobic bacterial endospores	1.7-5.0	Vandeweyer et al,. 2017a
Tenebrio molitor‡*	Bacterial endospores	4.8-9.1	Vandeweyer et al,. 2017a
Tenebrio molitor‡*	Yeast and mould count	4.2-7.5	Vandeweyer et al,. 2017a
Hermetia illucens†	*Bacillus cereus*	3.8^{2}	Wyants et al., 2019
Acheta domesticus‡*	Total aerobic count	7.9	Caparros megido et al., 2017
Acheta domesticus‡*	Yeast and mould count	4.8	Caparros megido et al., 2017
Acheta domesticus‡*	Total aerobic count	8.1-8.8	Vandeweyer et al,. 2017a
Acheta domesticus‡*	*Enterobacteriaceae*	7.2-8.3	Vandeweyer et al,. 2017a
Acheta domesticus‡*	Lactic acid bacteria	7.4-8.8	Vandeweyer et al,. 2017a
Acheta domesticus‡*	Aerobic bacterial endospores	2.6-4.9	Vandeweyer et al,. 2017a
Acheta domesticus‡*	Bacterial endospores	<3.0-5.5	Vandeweyer et al,. 2017a
Acheta domesticus‡*	Yeast and mould count	5.6-7.2	Vandeweyer et al,. 2017a

Insect species	Hazard	Load (log cfu/g)	Reference
Locusta migratoria‡*	Total aerobic count	7.8-8.6	Stoops et al., 2016
Locusta migratoria‡*	*Enterobacteriaceae*	7.1-7.6	Stoops et al., 2016
Locusta migratoria‡*	Bacterial endospores	3.3-3.8	Stoops et al., 2016
Locusta migratoria‡*	Lactic acid bacteria	7.6-85	Stoops et al., 2016
Locusta migratoria‡*	Yeast and mould count	5.0-5.4	Stoops et al., 2016

2 Bacterial levels in both fresh insects and substrate were consistent with those reported by other authors other than Bacillus cereus levels. Authors concluded there existed no exclusive correlation between the substrate's microbial composition and the microbial composition of the BSF larvae, and argue that these differences are caused by multiple other factors, including type of substrate, rearing practices and parental origin of the larvae.

Table B

Microbial levels for different processed edible insects (* potential EU food, ‡ potential pet food refer to EFSA, 2013).

Insect species	Hazard	Processing	Load (log cfu/g)	Reference
Tenebrio molitor‡*	Total aerobic count	1-min water (80-100c)	4.64	Caparros Megido et al., 2017
Tenebrio molitor‡*	Yeast and mould count	1-min water (80-100c)	<1.0	Caparros Megido et al., 2017
Tenebrio molitor‡*	Total aerobic count	Freeze dried	4.47	Caparros Megido et al., 2017

Insectspecies	Hazard	Processing	Load (log cfu/g)	Reference
Tenebrio molitor‡	Yeast and mould count	Freeze dried	<1.0	Caparros Megido et al., 2017
Tenebrio molitor‡	Moulds	Boiled and dried	2.21-2.30	Garofalo et al., 2017
Tenebrio molitor‡	Mesophilic aerobes	Boiled and dried	2.6-.4.8	Osimani et al., 2017c
Tenebrio molitor‡	*Enterobacteriaceae*	Boiled and dried	<1.0	Osimani et al., 2017c
Tenebrio molitor‡	Sulphite-reducing clostridia	Boiled and dried	1.5-4.0	Osimani et al., 2017c
Tenebrio molitor‡	*Staphylococcus aureus*	Boiled and dried	<1.0	Osimani et al., 2017c
Tenebrio molitor‡	*Bacillus cereus*	Boiled and dried	<1.0	Osimani et al., 2017c
Tenebrio molitor‡	Lactic acid bacteria	Boiled and dried	1.7-2.8	Osimani et al., 2017c
Tenebrio molitor‡	Yeasts and moulds	Boiled and dried	<1.0-2.4	Osimani et al., 2017c
Acheta domesticus‡	Total aerobic count	4-min blanched	4.39	Caparros Megido et al., 2017
Acheta domesticus‡	Yeast and mould count	4-min blanched	<1.0	Caparros Megido et al., 2017
Acheta domesticus‡	Total aerobic count	Freeze dried	4.05	Caparros Megido et al., 2017

Insectspecies	Hazard	Processing	Load (log cfu/g)	Reference
Acheta domesticus‡	Yeast and mould count	Freeze dried	<1.0	Caparros Megido et al., 2017
Acheta domesticus‡ (whole)	*Enterobacteriaceae, Clostridium perfringens spores* and moulds	Boiled and dried	<2.00	Garofalo et al., 2017
Acheta domesticus‡ (whole)	Mesophillic aerobes	Boiled and dried	4.01-4.50	Garofalo et al., 2017
Acheta domesticus‡ (whole)	Yeasts	Boiled and dried	4.52-5.10	Garofalo et al., 2017
Acheta domesticus‡ (powdered)	*Enterobacteriaceae*, lactic acid bacteria, *Clostridium perfringens* spores and moulds	Boiled and dried	<2.00	Garofalo et al., 2017
Acheta domesticus‡ (powdered)	Mesophilic aerobes	Boiled and dried	3.91-4.80	Garofalo et al., 2017
Acheta domesticus‡ (powdered)	Moulds	Boiled and dried	2.92-3.10	Garofalo et al., 2017
Acheta domesticus‡ (whole)	Mesophilic aerobes	Boiled and dried	4.2	Osimani et al., 2017c
Acheta domesticus‡ (whole)	*Enterobacteriaceae*, suplhite-reducing clostridia, *Staphylococcus aureus* and yeasts and moulds	Boiled and dried	<1.0	Osimani et al., 2017c

Insectspecies	Hazard	Processing	Load (log cfu/g)	Reference
Acheta domesticus‡ (whole)	*Bacillus cereus*	Boiled and dried	3.6	Osimani et al., 2017c
Acheta domesticus‡ (whole)	Lactic acid bacteria	Boiled and dried	2.1	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	Mesophilic aerobes	Boiled and dried	5.0	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	*Enterobacteriaceae*	Boiled and dried	3.1	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	Sulphite-reducing clostridia	Boiled and dried	2.8	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	*Staphylococcus aureus*	Boiled and dried	<1.0	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	*Bacillus cereus*	Boiled and dried	5.1	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	Lactic acid bacteria	Boiled and dried	5.5	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	Yeasts	Boiled and dried	2.0	Osimani et al., 2017c
Acheta domesticus‡ (powdered)	Moulds	Boiled and dried	3.3	Osimani et al., 2017c

Insectspecies	Hazard	Processing	Load (log cfu/g)	Reference
Gryllodes sigillatus‡	Total viable counts	Boiled	2.6	Vandeweyer et al., 2018
Gryllodes sigillatus‡	Total viable counts	Frozen (-20c)	2.4	Vandeweyer et al., 2018
Gryllodes sigillatus‡	Total viable counts	Oven dried (10 hours 80c)	4.3	Vandeweyer et al., 2018
Gryllodes sigillatus‡	Total viable counts	Smoked and dried	7.9^{3}	Vandeweyer et al., 2018
Schistocerca gregaria‡ (whole)	Mesophillic aerobes	Boiled and dried	4.1	Osimani et al., 2017c
Schistocerca gregaria‡ (whole)	*Enterobacteriaceae*, sulphite-reducing clostridia, *Staphylococcus aureus*	Boiled and dried	<1.0	Osimani et al., 2017c
Schistocerca gregaria‡ (whole)	*Bacillus cereus*	Boiled and dried	2.1	Osimani et al., 2017c
Schistocerca gregaria‡ (whole)	Lactic acid bacteria	Boiled and dried	2.4	Osimani et al., 2017c
Schistocerca gregaria‡ (whole)	Yeasts	Boiled and dried	2.0	Osimani et al., 2017c
Schistocerca gregaria‡ (whole)	Moulds	Boiled and dried	2.2	Osimani et al., 2017c

Authors associate this higher count to external contamination after treatment.

Table C

Composition variability for insects (DM= dry matter; * potential EU food, †potential EU feed, ‡ potential pet food refer to EFSA, 2013).

Species	Feed	Fibre	Fat	Protein	Ash	Moisture	Refer
Hermetia ilucens† (Larvae day 1)	Chicken feed	-	4.8%	56.2%	-	-	Liu et 2017
Hermetia ilucens† (Larvae day 14)	Chicken feed	-	28.4%	39.2%	-	-	Liu et 2017
Hermetia ilucens† (Pupa)	-	-	7.2%	43.8%	-	-	Liu et 2017
Hermetia ilucens† (Adults)	Chicken feed	-	21.6%	57.6%	-	-	Liu et 2017
Hermetia ilucens† (Larvae)	Vegetables	-	2%	14%	-	78%	Jucke al., 20
Hermetia ilucens† (Larvae)	Fruit	-	21%	12%	-	62%	Jucke al., 20
Hermetia ilucens† (Larvae)	Fruit and vegetables	-	12%	18%	-	62%	Jucke al., 20
Hermetia ilucens† (Larvae)	Plant-based	-	33.8%	-	5.1%	63.4%	Liu et 2017
Hermetia ilucens† (Larvae)	*Asophyllum nodosum*	-	8.1%	-	15.8%	76.9%	Liu et 2017

Species	Feed	Fibre	Fat	Protein	Ash	Moisture	Refer
Hermetia ilucens† (Larvae)	Fruit and vegetables (7:3)	17%DM	26.8%DM	41.8%DM	12.9%DM	-	Meneg et al., 2018
Hermetia ilucens† (Larvae)	Fruit	19.7%DM	40.7%DM	30.7%DM	7.2%DM	-	Meneg et al., 2018
Hermetia ilucens† (Larvae)	Winery by-products	17.7%DM	32.2%DM	34.4%DM	14.5%DM	-	Meneg et al., 2018
Hermetia ilucens† (Larvae)	Brewery by-products	8.7%	29.8%DM	52.9%DM	7.3%DM	-	Meneg et al., 2018
Hermetia ilucens† (Larvae)	Poultry feed	8.75%	4.02%	14.7%	-	66.5%	Nguye al., 20
Hermetia ilucens† (Larvae)	Pig liver	13.7%	8.39%	21%	-	55.3%	Nguye al., 20
Hermetia ilucens† (Larvae)	Fruit and vegetables	8.38%	2.2%	12.9%	-	71.8%	Nguye al., 20
Hermetia ilucens† (Larvae)	Rendered fish	12.7%	11.6%	19.4%	-	53.4%	Nguye al., 20
Tenebrio molitor†* (Larvae)	Brewery spent grains	12.54%	6.46%	13.22%	-	66.66%	Manci al., 20
Tenebrio molitor†* (Larvae)	Bread	6.09%	14.82%	10.73%	-	67.38%	Manci al., 20

Species	Feed	Fibre	Fat	Protein	Ash	Moisture	Refer
Tenebrio molitor† (Larvae)	Cookies	6.72%	17.77%	10.15%	-	64.45%	Manci al., 20
Tenebrio molitor† (Larvae)	Grains and cookies	11.26%	11.77%	13.44%	-	62.47%	Manci al., 20
Tenebrio molitor† (Larvae)	Bread and cookies	6.12%	17.48%	10.72%	-	64.66%	Manci al., 20

Table D

Key hazards identified in this literature review by insect species

Species: *Acheta domesticus*

Hazards identified:

Microorganisms (other than parasites)

- Aerobic bacteria (Caparros Megido et al., 2017, Vandeweyer et al., 2017a, Garofalo et al., 2017, Osimani et al., 2017c)
- Yeasts and moulds (Caparros Megido et al., 2017, Vandeweyer et al., 2017a, Garofalo et al., 2017, Osimani et al., 2017c)
- Lactic acid bacteria (Vandeweyer et al., 2017a, Garofalo et al., 2017, Osimani et al., 2017c)
- Bacterial endospores (Vandeweyer et al., 2017a, Garofalo et al., 2017, Osimani et al., 2017c)
- Enterobacteriaceae (Vandeweyer et al., 2017a, Garofalo et al., 2017, Osimani et al., 2017c)
- Staphylococcus aureus (Osimani et al., 2017c)
- Cronobacter sakazakii (Walia et al. 2018)

Parasites

- Isospora spp. (Ga??cki and Sokó?, 2019)

AMR genes

- tet(M) (Milanovi? et al., 2016)
- tet(K) (Milanovi? et al., 2016)
- tet(O) (Milanovi? et al., 2016)
- tet(S) (Roncoli et al. 2019)

Allergenicity: Cross-reactivity

- Tropomyosin (Pali-Schöll et al., 2019)

Species: *Hermetia ilucens*

Hazards identified:

Microorganisms (other than parasites)

- Bacillus cereus (Wynants et al., 2019)

Parasites

- Eimeria nieschulzi (Muller et al. 2019)
  Eimeria tenella (Muller et al. 2019)
  Ascaris suum (Muller et al. 2019)

Heavy metals accumulation:

- Cadmium (Biancarosa et al. 2018, Purschke et al. 2017)
- Arsenic (Biancarosa et al. 2018)
- Mercury (Biancarosa et al. 2018)
- Lead (Biancarosa et al. 2018, Purschke et al. 2017)
- Mycotoxins accumulation
- Aflatoxin B1 (Bosch et al. 2017)

Species: *Locusta Migratoria*

Hazards identified:

Microorganisms (other than parasites)

- Aerobic bacteria (Stoops et al., 2016)
  Yeasts and moulds (Stoops et al., 2016)
  Lactic acid bacteria (Stoops et al., 2016)
  Bacterial endospores (Stoops et al., 2016)
  Enterobacteria (Stoops et al., 2016)

Parasites

- Isospora spp. (Ga??cki and Sokó?, 2019)
  Balantidium spp. (Ga??cki and Sokó?, 2019)
  Entamoeba spp. (Ga??cki and Sokó?, 2019)

AMR genes

- tet(M) (Osimani et al., 2017b)
  tet(K) (Osimani et al., 2017b)
  bla(Z) (Osimani et al., 2017b)
  erm- (Osimani et al., 2017b)
  aac-aph (Osimani et al., 2017b)

Species: *Tenebrio molitor*

Hazards identified:

Microorganisms (other than parasites)

- Aerobic bacteria (Caparros Megido et al., 2017, Mancini et al., 2019a, Osimani et al., 2017c, Osimani et al., 2018a, Stoops et al., 2016, Vandeweyer et al., 2017a)
  Yeasts and moulds (Caparros Megido et al., 2017, Mancini et al., 2019a, Stoops et al., 2016, Vandeweyer et al., 2017a, Osimani et al., 2017c)
  Lactic acid bacteria (Mancini et al., 2019a, Osimani et al., 2017c, Osimani et al., 2018a, Stoops et al., 2016, Vandeweyer et al., 2017a)
  Bacterial endospores (Mancini et al., 2019a, Osimani et al., 2018a, Stoops et al., 2016, Vandeweyer et al., 2017a)
  Staphylococci (Mancini et al., 2019a, Osimani et al., 2017c)
  Enterobacteriaceae (Mancini et al., 2019a, Stoops et al., 2016, Vandeweyer et al., 2017a, Osimani et al., 2017c)

Parasites

- Isospora spp. (Ga??cki and Sokó?, 2019)
  Balantidium spp. (Ga??cki and Sokó?, 2019)
  Entamoeba spp. (Ga??cki and Sokó?, 2019)

AMR genes and substances

- tet(M) (Milanovi? et al., 2016)
  tet(S) (Milanovi? et al., 2016)
  tet(K) (Milanovi? et al., 2016)
  erm(B) (Osimani et al., 2017a)
  aac-aph (Osimani et al., 2017a)
  Chitosan (Shin et al., 2019)

Heavy metals accumulation

- Cadmium (Bednarska and ?wi?tek 2016, van der Fels-Klerx et al. 2016)
- Zinc (Bednarska and ?wi?tek, 2016)
- Arsenic (van der Fels-Klerx et al. 2016)
- Lead (van der Fels-Klerx et al. 2016)

Mycotoxins accumulation

- Aflatoxin B1 (Bosch et al. 2017)

Pesticides accumulation

- Diflufenican (Houbraken et al., 2016)
  Fenpropimorph (Houbraken et al., 2016)
  Isoproturon (Houbraken et al., 2016)
  Linuron (Houbraken et al., 2016)
  Mefenoxam (Houbraken et al., 2016)
  Pendimethalin (Houbraken et al., 2016)
  Pyrimethanil (Houbraken et al., 2016)
  Tebuconazole (Houbraken et al., 2016)

Allergenicity: cross-reactivity

- Apolipophorin-III (Barre et al., 2019)
  Larval cuticular protein (Barre et al., 2019)
  Hemolymph protein (Barre et al., 2019)
  Tropomyosin (Pali-Schöll et al., 2019, Broekman et al., 2016)

Species: *Schistocerca gregaria*

Hazards identified:

Microorganisms (other than parasites)

- Aerobic bacteria (Osimani et al., 2017c)
  Yeasts and moulds (Osimani et al., 2017c)
  Bacillus cereus (Osimani et al., 2017c)
  Enterobacteriaceae (Osimani et al., 2017c)
  Staphylococcus aureus (Osimani et al., 2017c)

Allergencity: cross-reactivity

- Tropomyosin (Pali-Schöll et al., 2019)

Species: *Blattodea spp.*

Hazards identified:

Parasites

- Isospora spp. (Ga??cki and Sokó?, 2019)
  Balantidium spp. (Ga??cki and Sokó?, 2019)
  Entamoeba spp. (Ga??cki and Sokó?, 2019)

Species: *Musca domestica*

Hazards identified:

Microorganisms (other than Parasites)

- Salmonella enterica (Pava-ripoll et al. 2015)
  Cronobacter sakazakii (Pava-ripoll et al. 2015)
  Escherichia coli 0157:h7 (Pava-ripoll et al. 2015)
  Listeria monocytogenes (Pava-ripoll et al. 2015)

Species: *Bombyx mori*

Hazards identified:

AMR genes

- tet(S) (Milanovi? et al., 2016)
  tet(K) (Milanovi? et al., 2016)
  bla(Z) (Milanovi? et al., 2016)
  BmGlv2 (Shin et al., 2019)

Heavy metals accumulation

- Arsenic (Feng et al. 2019)
- Cadmium (Feng et al. 2019)
- Lead (Feng et al. 2019)