

APPROVED: 31 August 2022

doi: 10.2903/j.efsa.2022.e200909

Insects in food and their relevance regarding allergenicity assessment

Lidia Delgado Calvo-Flores¹, Cristiano Garino¹, Francisco Javier Moreno² and Hermann Broll¹¹Unit Effect-based Analytics and Toxicogenomics, Federal Institute for Risk Assessment (BfR), Berlin, Germany²Instituto de Investigación en Ciencias de la Alimentación, CIAL (CSIC-UAM), Madrid, Spain

Abstract

Within the European Green Deal, the 'Farm-to-Fork' strategy aims to accelerate the transition to a sustainable food system and to make food systems fair, healthy and environmentally friendly. Insects contribute to the circularity of agriculture, and are ideal candidates to complement traditional sources of protein. In this context, a working programme within the European Food Risk Assessment (EU-FORA) Fellowship Programme framework was developed at the German Federal Institute for Risk Assessment in collaboration with the Spanish National Research Council. The purpose of this technical report is to describe the activities in which the fellow was involved. As part of the training, the fellow performed a literature search regarding insects as food and allergenicity resulting in 493 hits. Out of the literature search a comprehensive scientific database with 200 publications has been built using the application 'EndNote'. Furthermore, an extensive scientific review with the title 'Sustainable food systems: EU regulatory framework and contribution of insects to the Farm-to-Fork strategy' approaching several important issues regarding insects (Regulatory frame, Market situation, Labelling and Control, Application as food/feed, Consumer acceptance and Allergenicity risk assessment) has been drafted and sent for publication in a peer reviewed journal. In order to analyse the impact of food processing on the allergenicity of insects, different food samples were prepared and artificially digested using a protocol simulating the gastrointestinal tract. Further laboratory work to analyse the readouts, including enzyme-linked immunosorbent assay (ELISA), has been discussed and proposed, scheduled for the end of July. In conclusion, the present working programme, together with additional activities and training provided by different institutions, enabled the fellow to gain a broader perspective in food safety, particularly concerning insects as novel foods and their safety assessment.

© 2022 Wiley-VCH Verlag GmbH & Co. KGaA on behalf of the European Food Safety Authority.

Keywords: allergen, allergenicity risk assessment, entomophagy, food safety, insects, novel food, tropomyosin

Correspondence: eu-fora@efsa.europa.eu

Declarations of interest: If you wish to access the declaration of interests of any expert contributing to an EFSA scientific assessment, please contact interestmanagement@efsa.europa.eu.

Acknowledgements: This report is funded by EFSA as part of the EU-FORA programme. The fellow wishes to specially thank the following for their support: Hermann Broll, Francisco Javier Moreno, Cristiano Garino, Cristina Alonso Andicoberry, Christoph Unger and Kei Udagawa.

Suggested citation: Delgado Calvo-Flores L, Garino C, Moreno FJ and Broll H, 2022. Insects in food and their relevance regarding allergenicity assessment. EFSA Journal 2022;20(S2):e200909, 9 pp. <https://doi.org/10.2903/j.efsa.2022.e200909>

ISSN: 1831-4732

© 2022 Wiley-VCH Verlag GmbH & Co. KGaA on behalf of the European Food Safety Authority.

This is an open access article under the terms of the [Creative Commons Attribution-NoDerivs](#) License, which permits use and distribution in any medium, provided the original work is properly cited and no modifications or adaptations are made.



The EFSA Journal is a publication of the European Food Safety Authority, a European agency funded by the European Union.



Table of contents

Abstract.....	1
1. Introduction.....	4
1.1. European food risk assessment fellowship programme	4
1.2. General information on the project	4
2. Description of work programme	5
2.1. Aims.....	5
2.2. Activities/Methods	6
2.2.1. Literature review and establishment of a database about insects as food and feed.....	6
2.2.2. Preparation of a scientific review regarding insects and its regulatory framework	6
2.2.3. Experimental work on the effect of food processing on the allergenicity of insect proteins	6
2.2.4. EU-FORA fellowship supporting programme.....	7
3. Conclusions.....	8
3.1. Conclusions regarding insects in food and their relevance regarding allergenicity risk assessment.....	8
3.2. Conclusions regarding the participation in the EU-FORA fellowship	8
References.....	9
Abbreviations	9

1. Introduction

1.1. European food risk assessment fellowship programme

The European Food Risk Assessment (EU-FORA) Fellowship Programme is a key initiative organised by the European Food Safety Authority (EFSA) to ensure preparedness for future risk analysis needs. The aim of the programme is to increase the pool of food safety risk assessment experts in Europe and stimulate the involvement of Member States in risk assessment, all with the ultimate objective of building a common EU culture for risk assessment.

The EU-FORA fellow participated in the general work programme entitled 'Insects in food and their relevance regarding allergenicity assessment'. This project brings together the expertise from the German Federal Institute for Risk Assessment (BfR) Unit Effect-based Analytics and Toxicogenomics (Unit 51) and from the Spanish National Research Council (CSIC) to generate knowledge on the allergenic risk using insects as food.

The work programme comprised the elaboration of a detailed scientific review covering different aspects of the use of insects as food and feed, highlighting its regulatory framework in the European Union. Also, the implementation of different protein-based techniques to be used in the analysis of *in vitro* (mainly, proteolysis studies) tools for the identification and assessment of potentially allergenic foodstuff derived from insects.

In addition, the programme proposed the exploration of the usefulness of more refined and advanced *in silico* approaches to assess the safety assessment of proteins. These novel approaches are not currently implemented by regulatory authorities but there are ongoing projects addressing these new tools with the aim of moving further the field of allergenicity risk assessment of novel proteins. Concretely, improved *in silico* analysis approaches based on more advanced bioinformatics tools that might better predict the risk of a novel protein to trigger toxic or allergic reactions.

1.2. General information on the project

The Farm-to-Fork strategy is a crucial part of the European Green Deal regarding the agri-food chain. By implementing the objectives of the strategy, insects as food and feed can significantly contribute to the improvement of the sustainability from Farm to Fork. A significant aspect is the promotion of the production and usage of new protein sources that can help to relieve pressure on agricultural land. Insect farming can reduce the need of importing some food and feed commodities by expanding the spectrum of products with high content of protein available in the EU, while shortening the agri-food chain. Globally more than 2,000 insect species have been documented in the literature as edible. The most commonly eaten insects are members of the Coleoptera (beetles), Lepidoptera (Caterpillars of butterflies and moths), Hymenoptera (bees, wasps, ants), Orthoptera (grasshoppers, locusts, crickets, termites), Hemiptera (cicadas, leaf and plant hoppers, true bugs, scale insects), Odonata (dragonflies) and Diptera (flies) families (Van Huis et al., 2013; Jongema, 2017). At present, several dossiers for different insect species are waiting the safety assessment carried out by EFSA and the market authorisation as novel foods (Regulation (EU) No 2015/2283) and six insect preparations from *Tenebrio molitor*, *Acheta domesticus*, *Locusta migratoria* and *Alphitobius diaperinus* have already been approved by the European Commission. However, there can be hazards associated with insects for use in food and feed depending on species, feed, production and processing conditions (Schlüter et al., 2017; Testa et al., 2017) and, in its scientific opinions, EFSA concluded that further research on the allergenicity of insects is needed.

To date, little information is publicly available about the hazards associated with insects for use in food and feed. However, the scarce information available indicates that insect proteins can cause allergic reactions in humans and animals with allergy to other arthropods, such as crustaceans (e.g. shrimp, prawn and crab) and house dust mites, due to allergen cross-reactivity (de Gier and Verhoeckx, 2018; Premrov et al., 2021). This is also reflected in the scientific opinions on insect species as food by the EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA) published so far (Safety of frozen and dried formulations from whole yellow mealworm (*Tenebrio molitor* larva) as a novel food pursuant to Regulation (EU) 2015/2283; Safety of dried yellow mealworm (*Tenebrio molitor* larva) as a novel food pursuant to Regulation (EU) 2015/2283; Safety of frozen and dried formulations from migratory locust (*Locusta migratoria*) as a novel food pursuant to Regulation (EU) 2015/2283; Safety of frozen and dried formulations from whole house crickets (*Acheta domesticus*) as a Novel food pursuant to Regulation (EU) 2015/2283; Safety of partially defatted house cricket (*Acheta*

domesticus) powder as a novel food pursuant to Regulation (EU) 2015/2283; Safety of frozen and freeze-dried formulations of the lesser mealworm (*Alphitobius diaperinus* larva) as a Novel food pursuant to Regulation (EU) 2015/2283.

Cross-reactivity can be explained because many proteins occurring in currently consumed edible insects are phylogenetically related to allergens widely dispersed in the different groups of arthropods (crustaceans, insects, mites) and molluscs, as it is the case of pan-allergens such as tropomyosin, enolase, alpha-actin or arginine kinase, among others (Barre et al., 2014). Besides pan-allergens, some proteins belonging to distinct protein families, including apolipoprotein III, the chemosensory protein, the cockroach allergen-like protein, hexamerin, the larval cuticle protein, the receptor for activated protein kinase and the odorant-binding protein, among others, have arisen as proteins very specific for edible insects (Barre et al., 2021; He et al., 2021). These proteins, lacking or much less represented in other groups of arthropods, molluscs or nematodes, share well-conserved amino acid sequences and highly similar quaternary structures. Consequently, they have been recently proposed as probes for the specific detection of insect proteins added either intentionally as food ingredients or involuntarily as hidden allergens to food products in complement to other detection methods (Gautreau et al., 2017). Therefore, there is a need to assess their food safety, especially for people allergic to edible insects. Likewise, recently several anaphylactic reactions have been reported in Europe and America after consumption of certain insect species (i.e. yellow mealworm *T. molitor* and silkworm pupae *B. mori*) from individuals whose clinical history consisted exclusively of allergy to house dust mites (Beaumont et al., 2019) without any previous reported allergy (Gautreau et al., 2017), indicating that the consumption of insects may also induce primary sensitisation in previously non-allergic individuals (Garino et al., 2020). This was confirmed in professional mealworm breeders sensitised after occupational exposure and showing allergic symptoms upon in food challenges with *T. molitor* (Broekman et al., 2017).

Consequently, there is a need to undertake an assessment of the allergenic potential of insects intended for human consumption (EFSA NDA Panel, 2021) in particular because only limited or no history of human consumption at all of insects has been demonstrated so far in the EU. Risk assessment includes an examination of the protein content of insects; an evaluation of the degree of sequence homology of the protein components with known allergens, and immunological assays to identify potential allergenic components.

As part of a comprehensive assessment, the *in vitro* digestion of potential allergenic proteins is considered a useful test to support the weight-of-evidence approach applied today for allergen risk assessment. Recently, the GMO Panel has assessed the usefulness of *in vitro* protein digestibility tests in allergenicity and protein safety assessment (EFSA GMO Panel, 2021).

2. Description of work programme

2.1. Aims

A literature search will be conducted to identify the number of insects and insect material already consumed in the EU and all aspects regarding the safe consumption of insect material. The final goal will be the compilation of all relevant research data regarding the safety of insects as food or food ingredients and its potential consumption in the EU.

The practical training programme consists of:

- i) insect sample management.
- ii) selecting appropriate insect's allergens.
- iii) preparation of an *in vitro* model that allow studying protein digestion.
- iv) analysing readouts.
- v) preparing a report and contributing to a publication.

Special emphasis will be put on internationally accepted *in vitro* digestion models to be used so that the scientific output can be put in comparison with already existing systems. In this way, the project spans the bridge between bioinformatics, basic research, practical experience and law enforcement requirements so that the fellow will gain insights into all functionalities and aspects of these modules. At the end, the fellow will gain practical experience using different modern laboratory techniques and get trained in conducting a scientific literature search applied to a specific research question on insects' consumption and allergy risk assessment. The preparation of scientific publications will be supported

and accompanied by experienced mentors. Finally, a publication shall have a positive impact on the fellows' personal career.

The research proposal consists of two interacting parts, a literature review regarding the consumption of insects and related aspects; and the practical research using insect proteins in *in vitro* digestion systems aiming to generate new data on the risk assessment of insect as a potential allergic food.

2.2. Activities/Methods

2.2.1. Literature review and establishment of a database about insects as food and feed

During the first 3 months of the fellowship, a literature search regarding insects as food and allergenicity was created and conducted resulting in 493 hits in the following databases: Science Direct, Scopus, PubMed, Web of Science and Google Scholar. Out of the literature search a comprehensive scientific database with 200 publications has been built using the application 'EndNote'. A system of classification into several thematic groups (EU legislation, General issues, Feed, Cross Reactivity, Processing, Bioinformatics, Nutrition, Risk Assessment, Allergenicity, Tropomyosin, Arginine-Kinase) has been used to classify the publications and facilitate the user-friendly navigation through the database.

2.2.2. Preparation of a scientific review regarding insects and its regulatory framework

The European Green Deal is a set of policy initiatives of the EU that aim to make Europe the first climate-neutral continent by 2050. Within this Deal, the 'Farm-to-Fork' strategy aims to accelerate the transition to a sustainable food system and to make food systems fair, healthy and environmentally friendly. Insects contribute to the circularity of agriculture, and are ideal candidates to complement traditional sources of protein. The placement of insects on the EU food market needs to be authorised by the Commission following a risk assessment. To date, three insect species have been approved for their commercialisation, while the use of insect proteins in feed is strictly regulated. Insect farming is an expanding industry in Europe, and more consumers are willing to try insect-based foods. To consolidate the insect market, it is also very important to assure the safety of eating insects. EFSA is the body in charge of assessing the microbiological and chemical risks related to the production and consumption of insects as food. Aside from the risks posed by contaminants or pathogens, insects consumed as food may be a threat for certain allergic consumers, who might develop an adverse reaction mainly due to a cross-reactivity to crustaceans and/or house dust mites. The European insect's market is also analysed, with a special emphasis on the regulatory aspects and on the safety assessment. Furthermore, an updated overview on the consumer acceptance is presented. Overall, the entry of insects into the EU market represents a great opportunity for the economic and ecological growth of the Community; however, consumers need to be exhaustively informed and protected from the hazards that these novel products might cause.

2.2.3. Experimental work on the effect of food processing on the allergenicity of insect proteins

Ten different processed samples containing *Tenebrio molitor* larvae were prepared:

Grounded Dust

- 1) 5A-Brot 5% Extruding A + 95% wheat flour (5% extruded insect +95% flour)
- 2) 5C-Brot 5% Whole +95% wheat flour (5% whole insect +95% flour)
- 3) 20A-Brot 20% Extruding A + 80% wheat flour (20% extruded insect +80% flour)
- 4) 20C-Brot 20% Whole A + 80% wheat flour (20% whole insect +80% flour)

Canned Meat

- 1) B10% 80°C (10% insect treated at 80°C)
- 2) B10% 80°C (10% insect treated at 100°C)
- 3) B10% 80°C (10% insect treated at 121°C)

Processed Foods containing the insect

- 1) Krispies
- 2) Chips
- 3) Tortillas

After that, the samples were carried to the BAM (Federal Institute for Materials Research and Testing) in Berlin and artificially digested following the protocol reported by Sieg et al. (2020).

At the end of the procedure, three different samples corresponding to three stages of the digestion (salivary phase, gastric phase and intestinal phase) were collected and after enzyme inactivation, digested samples were freeze until further treatment.

To analyse the readouts of the artificial digestion, the fellow visited the CIAL (Research Institute for Food Sciences) in Madrid. Two samples (20A-Brot 20% Extrudant A +80% Weizenmehl (20% extruded insect +80% flour and 2)) and B10% 80°C (10% insect treated at 100°C) out of the 10 samples artificially digested were selected to perform pilot research. The main purpose was to assess the degradation of tropomyosin, the main allergenic protein in insects, and the impact in its immunoreactive properties. Therefore, an enzyme-linked immunosorbent assay (ELISA) was performed to evaluate the ability of the method to recognise insect tropomyosin. It is important to highlight at this point that the ELISA test was developed for the determination of crustacean tropomyosin and not insect tropomyosin. However, as no specific kit for insects exist so far, and due to the high degree of sequence similarity between the tropomyosin of insects and crustaceans, it was decided as the more promising option.

Furthermore, two predictive bioinformatics tools have been used to complete the allergenicity analysis of *Tenebrio molitor*'s tropomyosin. AllergenOnline is an online tool where the protein sequence of interest can be compared with well-known allergens in their database, if the identity matches greater than 50% indicates possible cross-reactivity. A precautionary search using a sliding window of 80 amino acid segments of each protein can also be used to find identities greater than 35%, what according to CODEX Alimentarius guidelines 2003 means that IgE cross-reactivity between the newly expressed protein and a known allergen should be considered a possibility (FAO, 2009; EFSA GMO Panel, 2017). The second tool is PeptideCutter from ExPASy, that allows the prediction of potential cleavage sites cleaved by proteases or chemicals in a given protein sequence.

The analysis of results is not included in this report to avoid certain copyright claims, as the authors aim to publish them in other scientific journals. Further research on the results as well as new experimental work, including western blotting, will be performed before the end of the fellowship.

2.2.4. EU-FORA fellowship supporting programme

At the starting of the fellowship, the fellow was introduced to the activities performed at the Department of Food Safety of the BfR and at the hosting unit (Unit of Effect-based Analytics and Toxicogenomics). The fellow obtained experience in the area of insects as novel foods by performing an initial literature review followed by a complete scientific review on the EU regulatory framework of insects and their contribution to the Farm-to-Fork strategy.

The fellow also gained experience *in vitro* digestion models and further processing of readouts to assess allergenicity of insect's proteins.

The above work was completed under thorough guidance and effective supervision provided through fortnightly meetings conducted *in situ* or online. Apart from the practical work at the BfR during the fellowship year, the fellow participated in the following activities described in Table 1.

Table 1: Supporting activities during the EU-FORA fellowship programme

Trainings	Dates
Training Modules provided by EFSA	
Induction training: Microbiological and Chemical Risk Assessment, EFSA (Virtual)	30 August–17 September 2021
Training Module 1: Risk Assessment of other Food Areas, AGES (Virtual)	22–26 November 2021
Training Module 2: Risk Communication, BfR (Virtual)	21–25 March 2022
Training Module 3: Emerging Risks, EFET (On site)	6–10 June 2022
Training Module 4: Data Collection and Reporting, EFSA (Virtual)	22–25 August 2022

Trainings	Dates
Other trainings/Workshops	
EFSA Summer: School Food Safety Aspects of Integrated Food Systems	28–30 September 2021
Workshop: Risk Assessment and Risk Management of Genetically Modified Organisms (GMO), BfR	9 November 2021
DISH Cluster event: Towards healthy and safe diet	6 April 2022
EFSA Online Stakeholder workshop on small particles and nanoparticles in food	31 March–1 April 2022
Conferences	
EIT Future of Food Conference 2021 (Virtual)	30 November–1 December 2021
One Health Conference, Brussels	21–24 June 2022
Other activities	
Regular meetings with supervisors (virtual and on site)	Fortnightly
Regular seminars organised by the Department of Food Safety of the BfR (virtual and on site)	Fortnightly
Presentation by the fellow's work at the department seminar (BfR)	1 February 2022

3. Conclusions

3.1. Conclusions regarding insects in food and their relevance regarding allergenicity risk assessment

When known allergenic structures, such as insect allergens, are already present in the novel food, a comparative assessment can be performed, and the scope of cross-reactivity explored. Among the key parameters to be evaluated are:

- the amino acid primary sequence homology to known allergens (through bioinformatics analysis);
- the secondary and tertiary structure (looking for conformational epitopes);
- the ability to bind specific IgEs (through *in vitro* assays such as ELISA or immunoblot) and to elicit an immune response (checking the biological activity through *in vitro* or *in vivo* tests).

For a comprehensive assessment, other parameters like thermal and chemical stability to food processing, as well as resistance to gastric and duodenal digestion need to be carefully evaluated. All together will contribute to the 'weight-of-evidence' of the allergenicity risk assessment that might be result in further analysis.

Furthermore, the EFSA Genetically Modified Organisms (GMO) Panel has recently published a scientific opinion addressing the identification of specific research needs to improve the allergenicity risk assessment of new proteins (EFSA GMO Panel, 2022). This document has highlighted some potential gaps on allergenicity prediction which could indicate that some of the methods included in the current weight-of-evidence approach for the allergenicity risk assessment could not be easily applicable to complex mixtures of proteins that often make up whole foods, such as insects. Among other issues, the EFSA GMO Panel has recommended the consideration of the clinical relevance, route of exposure and potential threshold values of food allergens, as well as the use of improved *in silico* analysis approaches based on more advanced bioinformatics tools that may better predict the risk of a novel protein to trigger allergic reactions. Likewise, the draft of a roadmap that (re)defines the allergenicity safety objectives and risk assessment needs will be required to address a series of key questions for risk assessors and risk managers.

3.2. Conclusions regarding the participation in the EU-FORA fellowship

During the year of the EU-FORA fellowship programme, the fellow learned general principles of risk assessment and gained experience in the risk assessment of novel foods, especially insects, improving also her skills in the systematic extraction, structuring and evaluation of relevant scientific data. Furthermore, the participation in the EU-FORA programme provided an exceptional opportunity for the fellow to become part of an international experts' network that is expected to be a valuable source of future professional support and to provide a basis for further collaboration.

References

- Barre A, Caze-Subra S, Gironde C, Bienvenu F, Bienvenu J and Rougé P, 2014. Entomophagie et risque allergique. *Revue Française d'Allergologie*, 54, 315–321.
- Barre A, Pichereaux C, Simplicien M, Burlet-Schiltz O, Benoist H and Rougé P, 2021. A proteomic- and bioinformatic-based identification of specific allergens from edible insects: probes for future detection as food ingredients. *Foods*, 10, 280.
- Beaumont P, Courtois J, Van der Brempt X and Tollenaere S, 2019. Food-Induced anaphylaxis to *tenebrio molitor* and allergens implicated. *Revue Française d'Allergologie*, 59, 389–393.
- Broekman HC, Knulst AC, den Hartog Jager CF, van Bilsen JHM, Raymakers FML, Kruizinga AG, Gaspari M, Gabriele C, Bruijnzeel-Koomen CAFM, Houben GF and Verhoeckx KCM, 2017. Primary Respiratory and Food Allergy to Mealworm. *Journal of Allergy and Clinical Immunology*, 140, 600–603.
- de Gier S and Verhoeckx K, 2018. Insect (Food) allergy and allergens. *Molecular Immunology*, 100, 82–106.
- EFSA GMO Panel (EFSA Panel on Genetically Modified Organisms), 2017. Guidance on allergenicity assessment of genetically modified plants. *EFSA Journal* 2017;15(6):4862 49 pp. <https://doi.org/10.2903/j.efsa.2017.4862>
- EFSA GMO Panel (EFSA Panel on Genetically Modified Organisms), 2021. Statement on *in vitro* protein digestibility tests in allergenicity and protein safety assessment of genetically modified plants. *EFSA Journal* 2021;19(1):6350, 16 pp. <https://doi.org/10.2903/j.efsa.2021.6350>
- EFSA GMO Panel (EFSA Panel on Genetically Modified Organisms), 2022. Scientific Opinion on development needs for the allergenicity and protein safety assessment of food and feed products derived from biotechnology. *EFSA Journal* 2022;20(1):7044, 38 pp. <https://doi.org/10.2903/j.efsa.2022.7044>
- EFSA NDA Panel (EFSA Panel on Nutrition, Novel Foods and Food Allergens), 2021. Scientific opinion on the safety of dried yellow mealworm (*Tenebrio Molitor* Larva) as a novel food pursuant to regulation (EU) 2015/2283. *EFSA Journal* 2021;19(1):6343, 29 pp. <https://doi.org/10.2903/j.efsa.2021.6343>
- FAO (Food and Agriculture Organization of the United Nations), 2009. *Foods Derived from Modern Biotechnology*. World Health Organization (WHO), Rome.
- Garino C, Mielke H, Knüppel S, Selhorst T, Broll H and Braeuning A, 2020. Quantitative allergenicity risk assessment of food products containing yellow mealworm (*Tenebrio molitor*). *Food Chem Toxicol*, 142, 111460.
- Gautreau M, Restuccia M, Senser K and Weisberg SN, 2017. Familial anaphylaxis after silkworm ingestion. *Prehosp Emerg Care*, 21(1), 83–85.
- He W, Li S, He K, Sun F, Mu L, Li Q, Yi J, He Z, Liu Z and Wu X, 2021. Identification of potential allergens in larva, pupa, moth, silk, slough and faeces of domestic silkworm (*Bombyx mori*). *Food Chemistry*, 362, 130231.
- Jongema, Y. *Worldwide List of Recorded Edible Insects*. Department of Entomology, Wageningen University & Research, The Netherlands, 2017.
- Premrov B, Zrimšek P, Kotnik T, Leonardi A, Krizaj I and Jakovac-Strajn B, 2021. Insect protein-based diet as potential risk of allergy in dogs. *Animals*, 11, 1942.
- Schlüter O, Rumpold B, Holzhauser T, Roth A, Vogel RF, Quasigroch W, Vogel S, Heinz V, Jäger H, Bandick N, Kulling S, Knorr D, Steinberg P and Engel KH, 2017. Safety aspects of the production of foods and food ingredients from insects. *Molecular Nutrition & Food Research*, 61, 1600520.
- Sieg H, Krause BC, Kästner C, Böhmert L, Lichtenstein D, Tentschert J, Jungnickel H, Laux P, Braeuning A, Fessard V, Thünemann AF, Luch A and Lampen A, 2020. Cellular effects of *in vitro*-digested aluminum nanomaterials on human intestinal cells. *ACS Applied Nano Materials*, 3, 2246–2256.
- Testa M, Stillo M, Maffei G, Andriolo V, Gardois P and Zotti CM, 2017. Ugly but tasty: a systematic review of possible human and animal health risks related to entomophagy. *Critical Reviews in Food Science and Nutrition*, 57, 3747–3759.
- van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P, 2013. *Edible Insects. Future Prospects for Food and Feed Security*, FAO Forestry Paper 171; Eds. FAO and Wageningen UR; Food and Agriculture Organization of the United Nations.

Abbreviations

AGES	Austrian Agency for Health and Food Safety
BAM	Federal Institute for Materials Research and Testing
BfR	Bundesinstitut für Risikobewertung (German Federal Institute for Risk Assessment)
CIAL	Research Institute for Food Sciences
CSIC	Spanish Research Council
EFET	Hellenic Food Authority
ELISA	enzyme-linked immunosorbent assay
EU-FORA	European Food Risk Assessment Fellowship Programme
GMO	genetically modified organism
IgE	immunoglobulin E