



Food safety concerns: A review on pathogenic microbes associated with common edible insects

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Key words

Entomophagy;
Edible Insects;
Food Safety;
Pathogenic Microbes

Abstract

This review explored the pathogenic microbes associated with common edible insects. With rising human populations and fluctuating food supplies, edible insects offer a rich source of protein, vitamins, and minerals and are culturally accepted in many regions. Despite their nutritional benefits, knowledge on microbial hazards associated with edible insects is fragmented. The review focuses on commonly consumed species, including *Tenebrio molitor*, *Zophobas morio*, *Acheta domesticus*, *Gryllus bimaculatus*, *Locusta migratoria*, *Ruspolia differens*, *Bombix mori*, *Bunaea alcinoe*, and *Oryctes monoceros*. A total of 43 pathogenic bacteria and 20 pathogenic fungi linked to these edible insect species were identified. The most frequently reported pathogenic bacteria are: *Escherichia coli*, *Salmonella* spp. *Staphylococcus aureus*, *Bacillus cereus*, and *Pseudomonas aeruginosa*. Whereas, *Aspergillus niger*, *Aspergillus flavus*, *Fusarium oxysporum*, *Aspergillus fumigatus* and *Chaetomium zeylanoides* were the most common pathogenic fungal species reported. Factors such as rearing conditions, feed quality, and handling practices significantly influence microbial risks. Research from Africa primarily addresses the safety of wild-harvested edible insects, while studies from Western countries mainly focus on farmed varieties. Additionally, the findings indicate that post-harvest processing methods such as drying, boiling, cooking, steaming, toasting, roasting, smoking, deep frying, blanching, and acidification greatly enhance the safety of edible insects. This review underscores the need for stringent safety measures and discusses the current state of entomophagy and the necessity for regulatory frameworks in Africa. It also highlights the existing knowledge gaps regarding microbial hazards. Finally, the study proposes strategies for the safe commercialization of edible insects, including improved food safety protocols and enhanced consumer education.

Introduction

Human population is increasing, and as a result, a sufficient level of food security has not been achieved globally. Several factors including food price fluctuations, political and economic instability, climate change, and changes in food consumption patterns are obstacles to the global aim of reducing hunger (Sorjonen 2022). Edible insects represent a valuable alternative protein source that could offer a solution to the increasing global food demand (Rumpold et al. 2014). Insects are rich in protein, fatty acids, vitamins, minerals and useful bio-active substances and are culturally accepted and valued as traditional parts of the human diet in many parts of the world (Ramos-Elorduy et al. 1997, Vantomme et al. 2004, Musundire et al. 2016). Various studies have reported the contribution of edible insects to food security. A total of 524 edible insect species have been reported in 34 African countries, with Central Africa

Republic constituting 185 of the total species, followed by Democratic Republic of Congo (51 species) and Zambia (33 species) being the main countries where insects are eaten (Ramos-Elorduy et al. 1997). In western Kenya, the lake flies, 'agoro' termites, black ants, crickets, and grasshoppers, form part of traditionally consumed meals, whereas in Uganda, grasshoppers contribute about 16,100 Kcal and 513 g of protein per person per annum (Ayieko et al. 2010, Mbabazi 2011). Nevertheless, in Tanzania, entomophagy has been given little attention, resulting in missed opportunities for sustainable food sources and nutritional benefits from edible insects.

Modern entomophagy is still at an early to medium stage and insects have been primarily taken as food because of the low cost particularly in months of food shortage to fill the protein gaps before crop harvests (DeFoliart 1999, Tang et al. 2019). Most of the edible

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Received 12 May 2025, Revised 20 August 2025, Accepted 30 November 2025, Published 29 December 2025

<https://doi.org/10.65085/2507-7961.1112>

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ISSN 0856-1761, e-ISSN 2507-7961

insects consumed in the world are collected seasonally from the wild (Caparros Megido et al. 2016), which can pose detrimental effects on both human and animal health, as well as the environment (Ramos-Elorduy et al. 1997). Insect farming creates opportunities for increased production and promotes a circular economy because many edible insect species have the capacity to utilize a wide variety of substrates, making it possible to use as food and agricultural by-products as insect feeds (Sorjonen 2022, Katabaro et al. 2024). Farmed insects usually feed on a wide range of inexpensive fodders with efficient energy transmission (Caparros Megido et al. 2016, Tang et al. 2019). In addition, farmed insects have high food conversion efficiency, with low emission of greenhouse gases, and require less breeding spaces compared with those of livestock (Halloran et al. 2016). Since time immemorial, many insects have been eaten, but only very few of them have been well researched, notably species belonging mainly to the orders Lepidoptera, Orthoptera, Coleoptera and to a small extent from the orders Isoptera, Homoptera, Hymenoptera, Heteroptera, Diptera and Odonota (van Huis 2013). In Africa, Asia, and Latin America, several insect species are currently being reared or semi-domesticated and some have shown high feed conversion efficiencies ranging from 50–70%, surpassing those of chicken (38–43%) and cattle (10–12%) (Ooninx et al. 2015, Caparros Megido et al. 2024). Nonetheless, research has shown that edible insects can be a source of biological hazards, including bacteria that cause foodborne diseases, and insect-based foods can become contaminated in all stages of production, delivery, and consumption (Klunder et al. 2012, Caparros-Megido et al. 2018, Galecki et al. 2023).

According to many researchers, insect rearing conditions and feed sources can promote development of specific pathogens. The risk of microbial contamination has been reported in many farmed edible species; the spore-forming bacteria and Enterobacteriaceae have been detected in fresh bodies of farmed mealworm (*Tenebrio molitor*) and cricket (*Acheta domesticus*) (Klunder et al. 2012). The work of Ssepuuya et al. (2019) and Labu et al. (2021) in Uganda reported the presence of pathogenic bacteria such as *Acinetobacter baumannii*, *Serratia marcescens*, *Bacillus cereus*, *Staphylococcus sciuri*, *Campylobacter* spp. *Clostridium* spp. *Pseudomonas* spp. in *Ruspolia differens*, an edible longhorned grasshopper mainly harvested from the wild. Several other pathogenic bacteria and fungi have also been detected associated with farmed insect such as *Tenebrio molitor* collected from Belgium and Netherlands (Stoops et al. 2016, Garofalo et al. 2016); orthopterans such as *Locusta migratoria*, *Acheta domesticus* and *Gryllus bimaculatus* from Thailand (Milanovic et al. 2018, Mitchaonthai et al. 2024). Most edible insects species are harvested from the wild without proper biosecurity; however, in China and other western countries, farmed insects have to meet additional food safety standards and guidelines, including control of foodborne pathogens (Belluco et al. 2018, Feng et al. 2018). Although, numerous guidelines have been developed to ensure that edible insects are reared under safe conditions and can be safely used in food and feed production in the in China, Canada, Europe and Thailand

(Sun 2015, HEALTH-CANADA 2016, DG-SANTE 2017, Preteseille et al. 2018) and to a small extent in South Africa, Kenya, Rwanda and Uganda (Niassy et al. 2018, Niassy et al. 2022), in most of African countries where the demand for insect protein is high, these guidelines are not available (Usman and Yusuf 2020, Lähteenmäki-Uutela et al. 2021).

Concerns on the safety of edible insect as food and food products have been extensively reviewed (Garofalo et al. 2019, Murefu et al. 2019, Cappelli et al. 2020). Researchers from different parts of the globe have explored the potential safety issues (biological, chemical, and environmental) associated with farmed, processed, and non-processed insects along the entire production chain, concluding that many factors can affect the safety of edible insects (Banjo et al. 2006, Klunder et al. 2012, Grabowski and Klein 2016, Walia et al. 2018). Such factors include: the species of insect reared, rearing and production methods, developmental and harvested stages and many other factors (Garofalo et al. 2019). Nevertheless, published information on the pathogenic microbes associated with edible insects is still fragmented. Therefore, this review provides information on the microbes pathogenic to humans associated with edible insects of the mainly consumed species (*T. molitor*, *Z. morio*, *A. domesticus*, *G. bimaculatus*, *L. migratoria*, *R. differens*, *B. mori*, *B. alcinoe* and *O. Monoceros*). The review further present analysis on the pathogenic microbe dynamics associated with the rearing of insects and the post-harvest treatment applied to edible insects to reduce the microbiological risks for consumers. For the economic and safe mass production and marketing of edible insects on industrial scale excessive research is required regarding cost-effective rearing methods and post-harvest processing technologies. The review further highlights the shortcomings of the current insect production systems and puts forward strategies to promote consumption of edible insects.

Materials and Methods

Search strategy

Literature search to identify published studies on the safety of edible insects was conducted between February to April, 2025. The literature search was focused on all biological hazards associated with consumption of edible insects. Furthermore, the purpose of the literature research was to identify possible intervention strategies to minimize microbe contamination of edible insects proposed in various previous studies. Online databases such as Science direct, PubMed, Scopus, Google scholar and Web of Science were used to search for relevant published scientific articles on the safety of edible insects. Grey literature (official documents in electronic formats) was accessed from relevant organization's websites. The following search strings were mainly used:

- Food Safety AND (Edible insect/novel food/mealworm/ crickets/ Orthoptera/ Lepidoptera/Coleoptera).
- Entomophagy AND (microbiota/microbes/microbial count/ microbial community/ microbial load/ microbial risk/microbial hazard/microbial safety microbiological risk).

- Edible insect AND (Processing/ Storage/ Treatment/ Rearing/ Harvesting/ Commercialisation)

The inclusion criteria used in identifying the relevant documents were as follows: the document, or part of the document, is about insect consumption, safety assessment of edible insects, biological/microbial hazards associated with edible insects, edible insect value chain, edible insects rearing, processing/treatment/storage and how these may affect safety of the product. All articles on insects belonging to the following orders: Orthoptera, Lepidoptera and Coleoptera were included, these orders encompass insects which are mainly consumed globally. However, only the following species: *T. molitor*, *Z.*

morio, *A. domesticus*, *G. bimaculatus*, *L. migratoria*, *R. differens*, *B. mori*, *B. alcinoe* and *O. Monoceros* were considered in this review. Among all the edible insects, these species are seen as more suitable for consumption and processing from different parts of the world (Table 1). Only articles published in English language were considered but no restriction regarding the publication year and status was enforced. Studies on non-pathogenic microbes to humans or pathogenic microbes in insect species beyond the scope of this review were excluded. The search results were first screened by title and abstract followed by full text reading and all duplications were excluded from the search results.

Table 1: Selected edible insects reared/ harvested from the wild at commercial scale

Species Name	Common Name	Stages utilized for food	Countries with high consumption	References
<i>Acheta domesticus</i>	house cricket	Adult (Farmed)	United States, Canada and European countries (Netherlands and Belgium), Thailand, Cambodia, Uganda, Kenya etc. Large-scale farming for protein products and snacks for human consumption.	(Mahavidanage et al. 2023, Weissman et al. 2012, Magara et al. 2021)
<i>Gryllus bimaculatus</i>	black cricket or field cricket	Adult (Farmed)	Thailand: One of the leading countries for black cricket farming. China: Significant production for both human consumption and animal feed. African countries such as Kenya and Uganda.	(Magara et al. 2021, Ragab et al. 2024)
<i>Locusta migratoria</i>	locust	Adult (Wild)	African countries like Mali, Niger, Kenya and Uganda harvest locusts during swarming events. Asian countries such as China and Thailand, locusts are consumed and also sold in local markets. Middle Eastern countries: Such as Morocco, where locusts are traditionally consumed.	(Hosni et al. 2024, Siddiqui et al. 2024)
<i>Ruspolia differens</i>	grasshopper	Adult (Wild)	East African countries such as Tanzania and Uganda are known for harvesting grasshoppers during the rainy season.	(Nabikolo et al. 2023, Mmari et al. 2017, Matojo and Hosea 2013)
<i>Tenebrio molitor</i>	meal worm (yellow meal worm beetle)	larvae (Farmed)	China, Thailand, United States, Netherlands: Significant commercial production for human food and animal feed.	(FAO 2013, van Huis 2013, Hong et al. 2020)
<i>Zophobas Morio</i>	giant meal worm	Larvae (Wild)	Asia (Thailand and Indonesia), North America and in European countries such as Germany, where they are farmed for various food products.	(Rakovitsky et al. 2024, Scholliers et al. 2020)
<i>Bombyx mori</i>	silk worm	Pupae (Farmed)	China: The largest producer of silkworms, both for silk and as food. India: Significant consumption of silkworm pupae in various regional cuisines.	(Rodri'guez-Ortiz et al. 2024, Brady et al. 2025)
<i>Oryctes monoceros</i>	rhinoceros beetle	Larvae (Wild)	Nigeria, Southeast Asian countries: Such as Thailand, Myanmar, Malaysia, Vietnam and Indonesia, where larvae are considered a delicacy.	(Banjo et al. 2006, Catley 1969)

<i>Bunaea alcinoe</i>	Larvae-Lepidoptera	Larvae (Wild)	Nigeria and Congo DRC, where these larvae are traditionally consumed, normally harvested during the rainy season.	(Amadi et al. 2005, Braide et al. 2011, Kusia et al. 2023)
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Data analysis

In the initial search a total of 1207 studies were identified from the following databases; Web of Science-345, Google Scholar-289, PubMed-400, Science Direct-53, Scopus-112 and 8 from Grey literature). Of these, 705 papers were retrieved after removal of duplicates and documents without full text availability (502). Of these, a final body of 97 articles, fulfilling the inclusion criteria, were identified for this review. The other publications (n

= 608) were discarded at different stages due to either reporting non-pathogenic bacteria, fungi, viruses or unclear presentation of the data or reporting insect species which were not considered in this review. The metadata for all the retrieved articles were processed in Microsoft office 2016 (excel and word), the summary of the search strategy is presented in Figure 1.

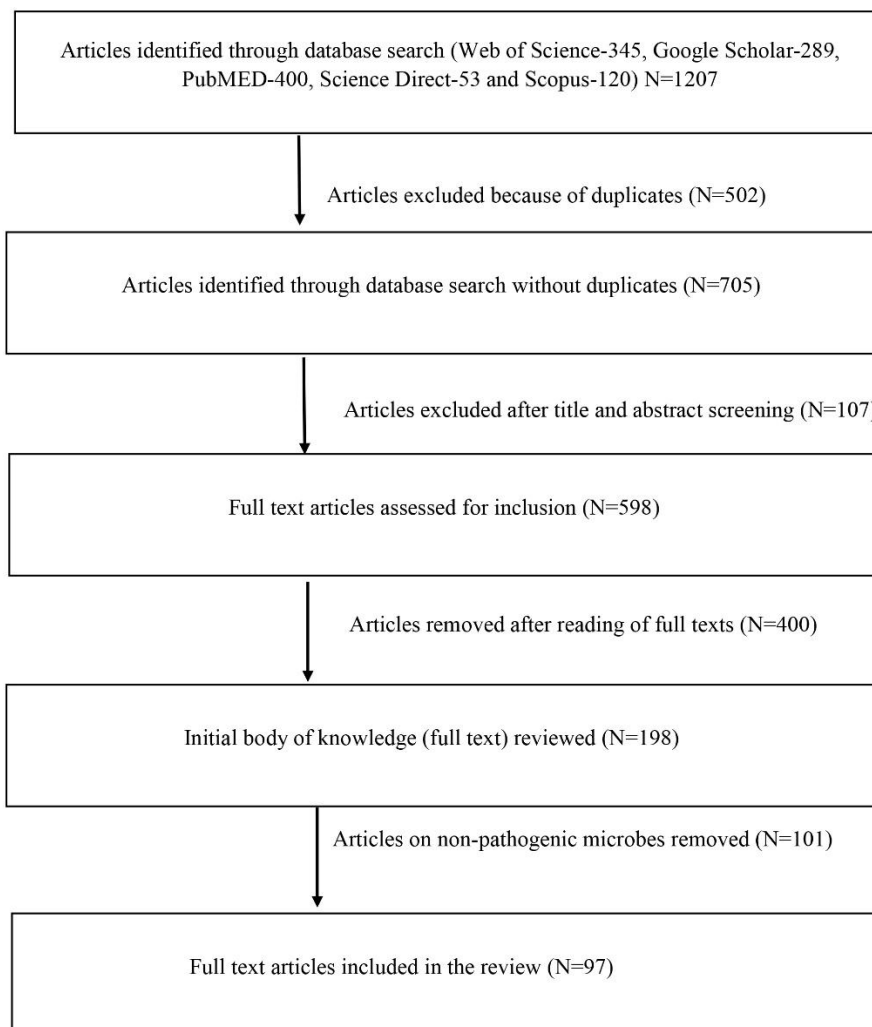


Figure 1: A flow chart showing summary of search strategy and results.

Results and Discussion

Search results

The review yielded a total of 97 articles which met the inclusion criteria. All articles reporting pathogenic microbes associated with the following insect species: (*T. molitor*, *Z. morio*, *A. domesticus*, *G. bimaculatus*, *L. migratoria*, *R. differens*, *B. mori*, *B. alcinoe* and *O. Monoceros*) were included in the final review. The review body was dominated by studies conducted in Africa (31), followed by Europe (29) and the reviews (22) with studies

conducted in multiple countries. Few studies were conducted in Asia, North and South America (Figure 2). The predominance of studies conducted in Africa reporting edible insects contaminated with pathogenic microbes could be attributed to lack of established guidelines to safeguard safety of insect food and feed compared to the western countries (Usman and Yusuf 2020, Lähteenmäki-Uutela et al. 2021). In Africa, insects are primarily taken as foods because they are free wild protein rich species (Tang et al. 2019), modern

entomophagy has not been utilized to its potential. In Canada, HEALTH-CANADA (2016) ensures the safety of novel food derived from plants and microorganisms such as insects. Similarly in Thailand there are established procedures and organizations to ensure the safety of edible insects (Preteuille et al. 2018) that could explain the few studies reporting insect food or products contaminated with pathogenic microbes. A total of 29 articles reported pathogenic microbes in edible insects from Europe, further analysis of these articles revealed that the consumption of whole insects is not preferred by Europeans (Hartmann and Siegrist 2016, Melgar-Lalanne

et al. 2019) due to neophobia (Caparros Megido et al. 2016), therefore efforts are made to re-purpose edible insects into preferred snacks such as cookies, breads and sausages. To ensure that, they undergo thorough check before final products, therefore several studies have been conducted to establish at what point contamination does occur (Klunder et al. 2012, Grabowski and Klein 2016, Vandeweyer et al. 2017). The review reports a total of 43 pathogenic bacteria and 20 pathogenic fungi species that were found associated with insect meals and/products, the results are presented in Tables 2 and 3.

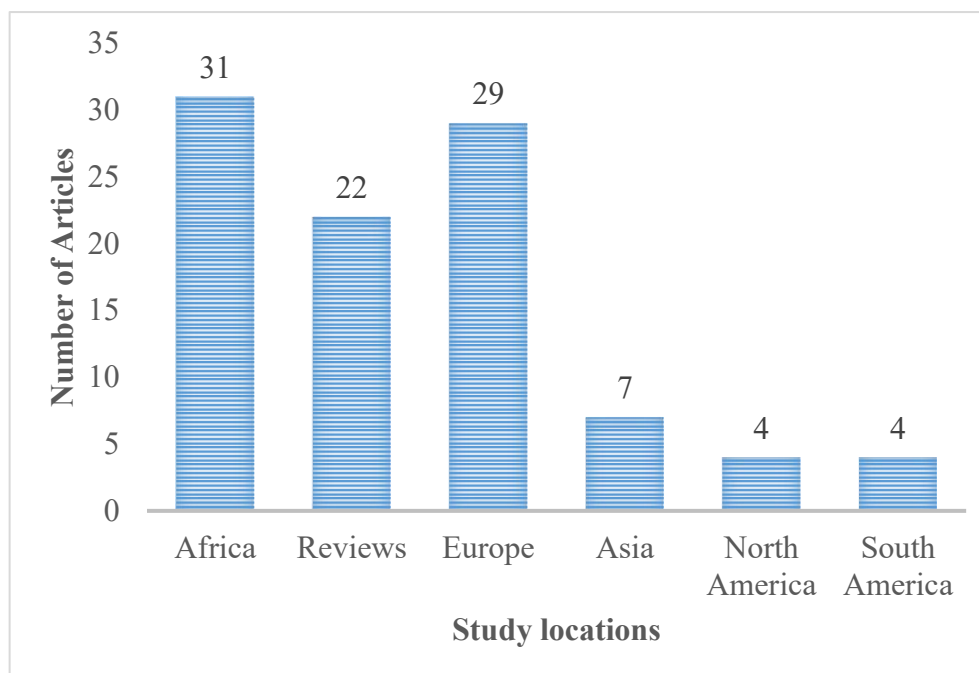


Figure 2: Distribution of the reviewed articles by continents/multiple continents (reviews)

Pathogenic bacteria species

A total of 43 pathogenic bacteria species were reported to be associated with edible insects/insect meals/ insect products. The species are: *Pseudomonas aeruginosa*, *Escherichia coli*, *Enterobacter* spp., *Klebsiella* spp., *Bacillus cereus*, *Aeromonas hydrophila*, *Aeromonas enteropelogenes*, *Aeromonas dhakensis*, *Aeromonas veronii*, *Enterococcus* spp., *Clostridiales* spp., *Pseudomonadaceae* spp., *Achromobacter* spp., *Citrobacter* spp., *Proteus* spp., *Staphylococcus* spp., *Tannerella forsythia*, *Rickettsiella* spp., *Micrococcus* spp., *Yersinia* spp., *Fusobacterium* spp., *Staphylococcus aureus*, *Clostridium perfringens*, *Cronobacter sakazakii*, *Listeria monocytogenes*, *Salmonella* spp. and *Erwinia* spp. (Table 2). Some insect species were reported to be associated with more pathogenic bacteria than others. For example, several pathogenic bacteria species were found associated with the two orthoptera species studied (*A. domesticus* and *G. bimaculatus*) recording 18 and 12 pathogenic bacteria species respectively (Table 2). Similarly, a total of 18 pathogenic bacteria species were found associated with *Tenebrio molitor*. It is important to also note that, there were overlaps with similar species of bacteria found to be associated with multiple species of edible insects, and some bacteria species appeared more

frequently than others, such species includes: *Bacillus cereus*- this was associated with 6 out of the 9 insect species studied. Other common bacteria species which were frequently encountered are: *Pseudomonas aeruginosa*, *Escherichia coli* and *Enterobacter* spp., each of these were recorded to be associated with 5 out of the 9 insect species studied. The following bacteria; *Klebsiella* spp., *Enterococcus* spp., *Clostridiales* spp., *Staphylococcus aureus*, *Salmonella* spp. and *Yersinia* spp. were also commonly reported (Table 2). Marshall et al. (2016) points out that insect microbiota consist of multiple common bacterial genera most of which are found naturally in production and processing environments and many species of these genera are not pathogenic to humans. Microbes found in the insect intestinal tract for example are thought to be mostly commensal and vary little among insect species and are non-pathogenic to humans (Klunder et al. 2012).

The three insect species: *A. domesticus*, *G. bimaculatus* and *Tenebrio molitor* are widely consumed as farmed insects for human protein source as well as for feed across the globe (Weissman et al. 2012, FAO 2013, van Huis 2013, Magara et al. 2021, Mahavidanage et al. 2023). Since these are reared insects, the possible explanation for their recorded high number of pathogenic bacteria species

could be attributed to the volume of research that has been conducted on these particular insect species. The species have been commercialized and are being exported to many places as food and feed, therefore the processed insect products have to meet the global standards for food safety (Preteville et al. 2018, DG-SANTE 2017, HEALTH-CANADA 2016) including the control of food-borne pathogens (Belluco et al. 2018). Therefore, extensive research has been conducted and documented the biological hazards associated with the three edible species (Klunder et al. 2012, Li et al. 2016, Stoops et al. 2016, Osimani et al. 2017, Milanovic et al. 2018, Mitchaothai et al. 2024, Nyombe et al. 2024) and their suitability for commercial production as food and feed. The other farmed insect is *Bombyx mori*, mainly produced for silk and food in China (Table 1), was reported to be associated with few species of pathogenic bacteria (*Bacillus cereus*, *Corynebacterium* spp.) and these were reported from one study only (Milanovic et al. 2018). The review shows that sources of microbial contamination in reared edible insects are; contaminated feed substrates such as food wastes and byproducts, rearing conditions such as poor hygiene, contaminated water, contact with contaminated soils and surfaces during rearing of insects (Klunder et al. 2012, Morales-Ramos et al. 2024). Other sources of contamination include poor handling, inadequate processing and the natural gut flora of an insect (Caparros-Megido et al. 2017, Vandeweyer et al. 2020).

On the other hand, the wild species: *Ruspolia differens*, *Bunaea alcinoe*, *Locusta migratoria*, *Zophobas morio* and *Oryctes monoceros* recorded relatively few species of pathogenic bacteria (Table 2). The highest number of pathogenic bacteria were recorded to be associated with *Ruspolia differens* (9 species) whereas *O. monoceros* and *Z. morio* had 3 and 1 pathogenic bacteria species respectively. It has been argued that, the number and type of microorganisms in foods is highly influenced by the environment where it originated but microbes can also be introduced along the handling chain (Belluco et al. 2013, Ssepuyya et al. 2019, Labu et al. 2021). In Africa, most edible insects are harvested seasonally from the wild at different developmental stages and used for food and feed (Amadi et al. 2005, Banjo et al. 2006, Nabikolo et al. 2023, Hosni et al. 2024). However, microbial contamination even in wild insects seem to occur along the food chain ranging from harvesting point, transportation, cleaning and processing (cooking, boiling, drying, toasting, deep frying) (Ng'ang'a et al. 2018). Furthermore, the rich nutritional value of edible insects coupled with other factors such as pH, moisture content, temperature and relative humidity, influence microbial survival and growth in foods (Klunder et al. 2012, Garofalo et al. 2019). It is important also to note that although infectious bacteria have been detected in edible insects, the role of these insects in disease transmission has not been established, only cases of allergic reactions and food borne illnesses have been reported.

Table 2: Pathogenic bacteria species associated with edible insects

Species Name	Country of origin	Bacteria species	References
<i>Zophobas morio</i>	Coleoptera	<i>P. aeruginosa</i>	(Maciel-Vergara et al. 2021)
<i>G. bimaculatus</i>	Orthoptera	<i>P. aeruginosa</i> , <i>E. coli</i> spp, <i>Enterobacter</i> spp, <i>Klebsiella</i> spp, <i>B.cereus</i> , <i>A. hydrophila</i> , <i>A. enteropelogenes</i> , <i>A. dhakensis</i> , <i>A. veronii</i> <i>Enterococcus</i> spp., <i>Clostridiales</i> spp., <i>Pseudomonadaceae</i> spp.	(Mitchaothai et al. 2024, Grabowski and Klein 2016, Nyombe et al. 2024, Maciel-Vergara et al. 2021, Vandeweyer et al. 2017)
<i>A. domesticus</i>	Orthoptera	<i>E. coli</i> (certain strains), <i>Achromobacter</i> spp., <i>Citrobacter</i> spp., <i>Enterobacter</i> spp., <i>Klebsiella</i> spp., <i>Proteus</i> spp., <i>Pseudomonas</i> spp., <i>Listeria</i> spp., <i>Staphylococcus</i> spp., <i>B. cereus</i> , <i>T. forsythia</i> , <i>Rickettsiella</i> spp <i>Enterococcus</i> spp., Enterobacteriaceae species., <i>Clostridiales</i> spp., <i>Micrococcus</i> spp., <i>Yersinia</i> spp., <i>Fusobacterium</i> spp.	(Mitchaothai et al. 2024, Garofalo et al. 2016, Nyombe et al. 2024, Osimani et al. 2017, Vandeweyer et al. 2017, Klunder et al. 2012, Giaccone 2005, Ulrich et al. 1981, Fernandez-Cassi et al. 2019)
Cricket powder (species-NS)	Orthoptera	<i>S. aureus</i> , <i>B. cereus</i> , <i>C. perfringens</i> , <i>C. sakazakii</i> , <i>E. coli</i> , <i>L. monocytogenes</i> , <i>Salmonella</i> spp.	(Walia et al. 2018)
<i>Tenebrio molitor</i>	Coleoptera	<i>Klebsiella</i> spp., <i>Erwinia</i> spp., <i>Enterobacter</i> spp., <i>Salmonella</i> spp., <i>C. thermopalmarium</i> , <i>S. aureus</i> , <i>Yersinia</i> spp., <i>Escherichia coli</i> , <i>Vibrio</i> spp., <i>Morganella</i> spp., <i>P. aeruginosa</i> , <i>B. cereus</i> , <i>P. agglomerans</i> , <i>Trabulsiella</i> spp., <i>S. haemolyticus</i> , <i>S. argenteus</i> , <i>E. corrodens</i> ,	(Garofalo et al. 2016, Osimani et al. 2017, Stoops et al. 2016, Li et al. 2016, Milanovic et al. 2018, Giaccone 2005)

Species Name	Country of origin	Bacteria species	References
		<i>Micrococcus</i> spp.	
<i>Ruspolia differens</i>	Orthoptera	<i>A. baumannii</i> , <i>S. marcescens</i> , <i>B. cereus</i> , <i>S. sciuri</i> , <i>Campylobacter</i> spp. <i>Clostridium</i> spp. <i>Pseudomonas</i> spp., <i>Neisseria</i> spp., Enterobacteriaceae species.	(Ssepuyaya et al. 2019, Labu et al. 2021, Ng'ang'a et al. 2018)
<i>Bunaea alcinoe</i>	Lepidoptera	<i>P. aeruginosa</i> , <i>P. mirabilis</i> , <i>S. aureus</i> , <i>B. cereus</i> , <i>E. coli</i> (certain strains), <i>S. mitis</i> .	(Braide et al. 2011, Amadi et al. 2005)
<i>Locusta migratoria</i>	Orthoptera	<i>Enterococcus</i> spp., <i>C. thermopalmarium</i> <i>S. aureus</i> , <i>S. haemolyticus</i> , <i>S. argenteus</i> , <i>E. corrodens</i>	(Osimani et al. 2017, Milanovic et al. 2018)
NS	Orthoptera	<i>E. coli</i> , <i>Salmonella</i> sp; Sulfite reducing clostridia spp.	(Ali et al. 2010)
<i>Oryctes monoceros</i>	Coleoptera	<i>S. aureus</i> , <i>P. aeruginosa</i> , <i>B. cereus</i> .	(Banjo et al. 2006)
<i>Bombix mori</i>	Lepidoptera	<i>B. cereus</i> , <i>Corynebacterium</i> spp.	(Milanovic et al. 2018)

NS-species name not stated

In cases where only a genus name is mentioned, one or more species within that genus (other than a species that also may be listed) can be pathogenic, species likely not identified by researchers of the original articles.

Pathogenic fungi species

The literature searches also indicated that a total of 20 pathogenic fungal species to be associated with edible insects. These species are: *Aspergillus flavus*, *Aspergillus tamari*, *Aspergillus toxicarius*, *Aspergillus sydowii*, *Aspergillus versicolor*, *Aspergillus jensenii*, *Aspergillus carneus*, *Aspergillus unguis*, *Aspergillus fumigatus*, *Aspergillus cristatus*, *Aspergillus amstelodami*, *Aspergillus intermedius*, *Rhodotorula mucilaginoso*, *Rhodotorula dairenensis*, *Trichosporon asahii*, *Aspergillus niger*, *Fusarium moniliforme*, *Candida zeylanoides*, *Debaryomyces hansenii* and *Fusarium oxysporum* (Table 3). Some insect species were found to be associated with many pathogenic fungal species than others, for example: *A. domesticus* recorded the highest number (9) followed by *R. differens* (5). Other insect species recorded relatively few pathogenic fungal species on average of three to two species for *G. bimaculatus*, *Bunaea alcinoe*, *Tenebrio molitor*, *Oryctes monoceros* and *Locust migratoria*. In general, studies about the fungal community associated with edible insects are few (Table 3), more studies are needed to fill this knowledge gap. Similar to bacteria, sources of pathogenic fungi in edible insects have been reported to include poor rearing conditions such as feed and or substrates especially in resource poor countries (Nyombe et al. 2024). Other sources of contamination are from the natural environment, including soil, vegetation, and decaying organic matter (Grabowski et al. 2017), this attest for fungal community which are mainly associated with wild insects.

The fungal community was dominated by species from the *Aspergillus* genera. The species in this genera are among the most abundant fungi worldwide, commonly found in soil, decaying vegetation, air and can grow over a wide range of temperatures (6-55°C for some species), high pH range and relatively low to high humidity

conditions (Krijgsheld et al. 2012). All these allow them to colonize various substrates rapidly. In connection to reared insects, the rearing conditions, such as temperature, humidity, and the presence of organic matter (feed and waste), can inadvertently favor the growth of *Aspergillus*. The feed used for rearing insects can also be a source of contamination for example; *Aspergillus flavus* has been detected in control feed used for rearing crickets (Fernandez-Cassi et al. 2020). Fungal species may also become associated with edible insects through poor processing, such as sun drying on the ground or in open environments, which are common practices in Africa (Mbata and Chidumayo 2003). *Aspergillus* species are known to produce mycotoxins, such as aflatoxins which can be a concern for food safety (Kachapulula et al. 2018). Several studies have indicated aflatoxins as cancer-causing, immunosuppressive mycotoxins that are associated with stunting, reduced weight gain, and rapid death (Gong et al. 2004, Lewis et al. 2005, Liu et al. 2012). Other fungal species of public health importance reported includes: *Aspergillus fumigatus* (irritation, allergy, asthma, pneumonitis, toxic effects, and a wide range of infections), *Aspergillus unguis* (respiratory health problems), *Aspergillus versicolor* (carcinogenic), *Aspergillus niger* (allergies, asthma, aspergillosis and sinusitis), *Aspergillus sydowii* (asthma and allergies), *Rhodotorula* spp. (fungemia, especially in immunocompromised individuals) (Soler-Hurtado et al. 2016, Spruijtenburg et al. 2024, Spagnolo 2025). The presence of these fungal species in edible insects poses a risk of increased aflatoxin contamination especially when they are poorly stored posing serious health-risks to consumers. Aflatoxins mitigation measures in place are mainly for major agricultural products including cereals, peanuts and crop by-products, with the increase in climatic changes and raise in temperature which favor the growth of fungi, there is need to extend stringent measures to include exposures originating from beyond agricultural commodities such as edible insects to ensure food safety (Kachapulula et al. 2018).

Table 3: Pathogenic fungal species associated with common edible insects

Species Name	Insect order	Fungal species	References
<i>G. bimaculatus</i>	Orthoptera	<i>A. flavus</i> , <i>A. tamari</i> , and <i>A. toxicarius</i>	(Nyombe et al. 2024)
<i>A. domestica</i>	Orthoptera	<i>A. sydowii</i> , <i>A. versicolor</i> , <i>A. jensenii</i> , <i>A. carneus</i> , <i>A. unguis</i> , <i>A. fumigatus</i> , <i>A. cristatus</i> , <i>A. amstelodami</i> , <i>A. intermedius</i>	(Nyombe et al. 2024, Osimani et al. 2017)
<i>Ruspolia differens</i>	Orthoptera	<i>R. mucilaginosa</i> , <i>R. dairenensis</i> , <i>T. asahii</i> . Yeasts and Molds-species NS	(Labu et al. 2021, Ng'ang'a et al. 2018)
<i>Bunaea alcinoe</i>	Coleoptera	<i>A. niger</i> , <i>F. moniliforme</i>	(Braide et al. 2011)
<i>Tenebrio molitor</i>	Coleoptera	<i>C. zeylanoides</i> , <i>D. hansenii</i>	(Osimani et al. 2017)
<i>Oryctes monocerus</i>	Coleoptera	<i>F. oxysporum</i> , <i>A. niger</i>	(Banjo et al. 2006)
<i>Locust migratoria</i>	Orthoptera	<i>A. cristatus</i> , <i>A. amstelodami</i>	(Osimani et al. 2017)

NS=Species not specified

In cases where only a genus name is mentioned, one or more species within that genus (other than a species that also may be listed) can be pathogenic, species likely not identified by researchers of the original articles.

Post-harvest treatment of edible insects to eliminate biological hazards

Table 4 presents information on various methods for processing edible insects in attempt to eliminate potential safety hazards such as pathogenic microbes. For the wild harvested edible insects; drying, boiling, cooking, steaming, toasting, roasting, smoking, frying and stewing are the common methods and sometimes two or more methods can be combined. In East Africa, *Ruspolia differens* also locally known as Senene by various tribes (Haya in Tanzania, Luo in Kenya, and Baganda in Uganda), boiling, stewing and cooking are the elemental methods for processing the species for human consumption (Mutungi et al. 2017, Ng'ang'a et al. 2018). In Nigeria, sun drying of the most consumed larvae (*Oryctes monocerus*) was efficient to reduce the microbial hazards. Whereas, in Germany, Belgium and Netherlands, technologies include drying (sun-drying, freeze-drying, oven-drying, fluidized bed drying, and microwave-drying), blanching, acidification, volumetric methods such as hydrostatic pressure and thermal treatments, and boiling/cooking under vacuum (Rumpold et al. 2014, Grabowski and Klein 2016, Caparros-Megido et al. 2018).

In general, very few studies have examined the effect of post-harvest processing of edible insect in relation to control of microbial hazard. Most studies have focused on the effect of processing and value addition on the nutrient quality, palatability, and sensory acceptability of insect-based products (Melgar-Lalanne et al. 2019, Akullo et al. 2025). In addition, studies have shown that post-harvest processing influences the nutritional content of the

insects. For example, toasting and solar drying decreased the in vitro protein digestibility and vitamin content of *Ruspolia differens* (Kinyuru et al. 2010), while smoking of *Oryctes monoceros* larvae, increased cholesterol concentrations from 20 % to 60% of the raw and smoke-dried samples respectively (Edijala et al. 2009).

Edible insects are underutilized, and issues of microbial safety remains a grey area particularly in Africa where much of the existing research concentrates on the safety of wild-harvested edible insects. Unlike reared edible insects, controlling microbial hazards of the wild-harvested species is more challenging than in controlled rearing environments (Matandirotya et al. 2022). In reared insects, the safety and quality of the food chain can be affected because of the close link between feed and food-borne pathogens such as *E. coli*, *S. aureus*, *B. cereus*, *Salmonella* spp. (Klunder et al. 2012, Walia et al. 2018). Reared edible insect can become contaminated with these pathogens as a result of their presence in feed. Therefore, during insect rearing, safe feed helps to reduce production costs, maintain or increase food quality and reduce feed and food losses and wastes. Contaminated feed has often resulted in food of animal origin being recalled and/or destroyed with significant economic losses for the livestock industries and a negative impact on food security (Makkar 2016). The reviewed articles (Table 4), have indicated that post-harvest treatments are crucial for ensuring the safety of edible insects. Implementing effective methods such as heat treatment, drying, chemical treatments, and irradiation can significantly reduce biological hazards. As the consumption of edible insects continues to rise, it is essential to establish and promote safe processing practices to protect consumer health.

Table 4: Possible routes of microbial contamination in insect food and treatment options

Insect species	Pathogen detected	Country of origin	Source of contamination	Treatment options	References
<i>Gryllus bimaculatus</i>	Enterobacteriaceae species. <i>Staphylococci</i> spp, <i>Bacilli</i> spp	Germany	Processing & Storage	Cooking between 10-30'; drying between 80-100°C	(Grabowski and Klein 2016)
<i>Oryctes Monocerus</i>	<i>S. aureus</i> , <i>P. aeruginosa</i> , <i>B. cereus</i>	Nigeria	Storage	Dying, Refrigeration	(Banjo et al. 2006)
<i>G. bimaculatus</i> & <i>A.domesticus</i>	<i>Enterococcus</i> spp., Enterobacteriaceae species, <i>Clostridiales</i> spp., <i>Pseudomonadaceae</i> spp.	Belgium	Production & Storage	NR	(Vandeweyer et al. 2017)
<i>Tenebrio molitor</i>	<i>Clostridia</i> spp., <i>Enterococcus</i> spp., Enterobacteriaceae species. <i>C. koseri</i> , <i>P. deceptionensis</i> .	Belgium	Production & Storage	NR	(Vandeweyer et al. 2017)
Cricket powder (NS)	<i>S. aureus</i> , <i>B. cereus</i> , <i>C. perfringens</i> , <i>C. sakazakii</i> , <i>E. coli</i> , <i>L. monocytogenes</i> , <i>Salmonella</i> spp	Cambodia	Rearing & Processing	Rearing in strict containment & boiling the porridge fortified with cricket powder	(Walia et al. 2018)
<i>A.domesticus</i> & <i>Tenebrio molitor</i>	Enterobacteriaceae species Bacterial spores	Netherlands	Rearing, Processing & storage	Acidification	(Klunder et al. 2012)
<i>Tenebrio molitor</i>	Gut microbiota	Germany	Rearing	Volumetric methods (hydrostatic pressure at 600 MPa and thermal treatments in a water bath at 90 °C)	(Rumpold et al. 2014)
<i>Tenebrio molitor</i>	Total aerobic count (TAC)	Belgium	Rearing	Boiling and cooking under vacuum	(Caparros-Megido et al. 2018)
<i>Ruspolia differens</i>	total viable aerobic count (TVC), Enterobacteriaceae, lactic acid bacteria, bacterial endospores, and yeasts and molds	Tanzania	Wild (harvesting, transportation, plucking, processing)	Deep-frying, toasting & smoking	(Ng'ang'a et al. 2018)

Commercialization of edible insects

Traditionally, insects have been part of the human diet in many parts of the world. Many African communities have a long history of consuming edible insects and approximately 2.5 billion people in the world currently supplement their diet with insects (van Huis 2013, 2016). Insects are mostly consumed in tropics, areas which are characterized by having high levels of biodiversity, suggesting that insect availability has influenced

consumption patterns (Lesnik 2017). Most edible insects are harvested from the wild, although semi-domestication and indoor farming have increased insect availability and the sustainability of production. However, modern entomophagy is still in its infant stage in many parts of Africa. Insect rearing presents significant economic potential because they can be harvested or farmed with relatively low investment thus providing an income source for rural communities. Insect domestication is

increasingly gaining attention, although only a limited number of species, such as bees, silkworms, and cochineals, can be regarded as fully domesticated, whereas most of edible insect species including the meal worms and crickets are classified as semi-domesticated (Vantomme 2015, Varelas and Langton 2017). In western countries, consumers are increasingly interested in innovative food products that incorporate insects in forms that are not easily recognizable. For instance, in Europe, when insects are processed into flours or powders and added to various items like energy drinks, cookies, and corn tortillas, they tend to gain more acceptance, unlike in Africa where whole insects are consumed in a perfectly recognizable form, either as snacks or as part of the daily diet (Hartmann and Siegrist 2016, Melgar-Lalanne et al. 2019). The incorporation of edible insects as food ingredients to enhance traditional foods has facilitated the commercialization of insect-based products that extend beyond merely flavored snacks. This strategy has created new opportunities to integrate insects into our daily diets while capitalizing on the environmental, technological, and nutritional benefits of insect farming. Successfully commercializing edible insects necessitates a comprehensive approach that will encompass consumer education, product innovation, adherence to safety regulations, and effective sustainability marketing.

Conclusion

Entomophagy offers a promising and sustainable solution to global food insecurity. However, the risks associated with pathogenic microbes demand immediate attention. Key findings indicate that microbial contamination poses significant risks, with common pathogens including *E. coli*, *Salmonella* spp., *S. aureus*, and several pathogenic fungi. This review presents factors such as rearing conditions, feed quality, and handling practices as the main sources of microbial contamination of edible insects. The review further highlights the critical need for comprehensive safety regulations and quality assurance measures specifically designed for insect farming and processing. The review also emphasizes that effective post-harvest processing methods of edible insects such as: boiling, freezing, drying and roasting, can significantly enhance safety. Future research should prioritize developing safe rearing methods, advancing processing technologies, and exploring the microbial dynamics within insect farming systems. This approach will help ensure that the advantages of entomophagy are realized while maintaining food safety standards.

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