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Review

Bacteria encountered in raw insect, spider, scorpion, and centipede taxa including edible species, and their significance from the food hygiene point of view

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ABSTRACT

Background: Insects, spiders, scorpions, and centipedes (non-crustacean arthropods; NCA) are consumed in most areas of the world. However, Western cultures generally do not practice this food habit (entomophagy) despite its advantages for the present and future of human nutrition. Little is known of the microbiological hazards associated with NCA consumption.
Scope and approach: The present review summarizes the bacteriological findings on raw arthropod taxa containing edible species. In a second step, it shows potential of bacteria to impair food hygiene and food safety for the human consumer by relating the bacteria found to human diseases.
Key findings and conclusions: Many bacterial species are known to affect invertebrates and humans alike (e.g. *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, and *Rickettsiella* spp.). Furthermore, insects can act as carriers for human pathogens if not obtained from a hygienic environment (e.g. salmonellae, *Campylobacter* spp., *Shigella* spp.). As with other foodstuffs of animal origin, exclusion of clinically-diseased specimens, hygienic obtention, washing and thorough heating seem suitable procedures to reduce the risk of food-borne diseases by bacteria, following the tradition of most NCA-consuming communities. Raw consumption of insects should be evaluated thoroughly, even when being traditional, because environmental changes could affect a previously valid innocuousness.

1. Introduction

Strictly spoken, entomophagy refers to consuming only insects, and the habit of consuming other NCA would be termed "arachnophagy", "scorpionophagy", and "chilopodophagy". "Anthropoentomophagy" states the human being as a consumer of insects. However, "entomophagy" will be used in the following due to reasons of practicability. Recently, FAO recognized (anthropo)entomophagy as one possibility to improve protein supply worldwide and considered commercial insect production a sustainable method to ensure this supply. With that, the traditional use of edible arthropods (i.e., gathering, cooking and preserving) is brought to a next level: commercial farming of those species that have a promising future as ordinary lifestock, typically a series of orthopteran (grasshoppers and crickets), coleopteran (beetle grubs), lepidopteran (butterfly caterpillars and pupae), dipteran (fly larvae and pupae), and hymenopteran (bee, ant, and wasp larvae and pupae) species (Van Huis et al., 2013).

In Europe, the current lack of an EU-wide hygiene legislation regarding edible insects has been interfering with the establishment of major insect production units as they were built in, among others, South-Eastern Asia (Hanboonsong, Jamjanya, & Durst, 2013). In 2014, Belgium and the Netherlands presented legal interim solutions (Federal Agency for Safety of the Food Chain, 2014; Hoge Gezondheidsraad, 2014; Netherlands Food and Consumer Product Safety Authority, 2014) to approach a sanitary control of edible insects. Both documents include a series of bacterial pathogens along with corresponding thresholds which are based on the data for minced meat and seafood. Regarding entomophagy legislation in the EU, 2015 was an important year. It saw the presentation of a scientific opinion on this foodstuff by the EFSA (2015), as well as a first reading of a legislative resolution regarding an amendment of the novel food regulation which will include insects (European Parliament, 2015) which was accepted in 2016 and will take effect by 2018.

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Besides prions and viruses, the EFSA statement addresses bacteria, fungi, and parasites, along with a series of non-infectional risks. Regarding bacteria and fungi, only traditional food-borne pathogens were mentioned, claiming that *E. coli*, *Salmonella* spp., or *Aspergillus* spp. were encountered in edible insects. However, and like in other farmed animals, the insect microbiome is complex and contains a great variety of different physiological and pathological microorganisms, i.e. some are vital symbionts for the insect in order to develop properly, while others are powerful entomopathogens used, among others, in the biological control of pest insects (Tanada & Kaya, 1993).

While invertebrate pathologists study diseases of these animals and human pathologists usually focus on diseases caused (or transmitted) by NCA, food hygienists evaluate the role of NCA as a source for food-borne diseases. From the latter point of view, it is less important whether a pathogen actually also causes disease in the NCA. However, zoonotic pathogens from asymptomatic NCA pose a higher risk for the consumer than those that actually cause clinical symptoms in the animals, for then there is a good chance that experienced gatherers and rearers recognize this condition of illness and exclude the affected animals from further processing.

The present review parts from the EFSA statements and focuses on the bacteriological findings of raw NCA, evaluating their potential risk for the human consumer. For that, an internet research was conducted using NCBI and Google Scholar. All scientific names of microorganisms were cross-checked using the "List of Prokaryotic names with Standing in Nomenclature" as available online.

So far, almost a million of different insect, about 100,000 different arachnid and approx. 3000 centipede species have been described, while the amount of edible NCA is estimated between 2000 and 3000 species. As a reference for the edible insects, the list by De Jongema (2015) was taken, in the case of other classes, the corresponding literature. In order to group NCA species, two mechanisms had to be (respectively were) used. On one hand, the data provided in the different publications regarding the identification of the NCA was sometimes relatively vague, (e.g. "beetles" or even "insects"). In the following, these generic terms are kept. On the other hand, some microorganisms were encountered in different, well-documented NCA species. In this case, the corresponding higher taxon (usually family or order) was used, as it seems likely that the pathogen may also interact with species of the same taxon.

2. Bacterial communities in non-crustacean arthropods

Basically, the arthropod flora consists of a taxon-specific, bacterial core community and a varying set of other microorganisms capable of reacting towards a series of changes during the lifetime of the animal (Tang et al., 2012). In this way, first extensive studies of the insect gut microbiome revealed that the phyla *Proteobacteria* and *Firmicutes* were the most prominent taxa, and that the diversity of the gut flora was greater in omnivorous than in strictly herbivorous or carnivorous insects. Other factors of influence are the habitat, the season, the feed, the instar, and the phylogeny (Feng, Wang, Zhou, Liu, & Wan, 2011; Jia et al., 2013; Tang et al., 2012; Yun et al., 2014). Regarding this latter factor, the microbiome has been used to clear evolutionary origins of certain insects (e.g. of termites [Dietrich, Köhler, & Brune, 2014]). Bacterial communities also influence oviposition behaviour (Zheng et al., 2013). Besides, shifts in the gut flora were observed as a response not to environmental changes, but also to pathological conditions, (e.g. by viruses, fungi, and nematodes [Chaston et al., 2011; Tang et al., 2012]). In addition and in parallel to other animals, the microbiome also includes probiotically-acting bacteria, e.g. *Lactobacillus* spp. and *Bifidobacterium* spp., as seen in Apini and Meliponini bees (Kwong & Moran, 2016; Vásquez et al., 2012).

These interactions were presented in an exemplified manner in the case of the honeybee (Grabowski & Klein, 2015a) and show that in the wild, NCA experience a constant uptake and release of microorganisms, depending on the environment and even the stage of development. Other expected transmission routes like food transfer seems to play a minor role (Kwong & Moran, 2016). This basic pattern, however, is likely to present itself also while farming NCA (typically insects), although microorganisms involved may vary greatly. Changes in the microbiome in relation to rearing conditions were observed (e.g. for the silkworm [*Bombyx mori*; Feng et al., 2011]).

3. Bacteria isolated from non-crustacean arthropods

The publications encountered originated mostly in the field of entomopathology, i.e. they considered the microorganism as found in living or dead, raw specimens, either encountered in their natural habitats or subjected to an artificial infection trial. This is important to stress and would correspond, from the food hygiene point of view, to the findings in raw meat of wild boars or mallards which were hunted for food. For the cross-check of clinical relevance, most data was published in medical journals.

According to the type of interaction, several risk classes were defined:

- Bacteria which are pathogenic to NCA and humans alike (class I)
- Bacteria which are pathogenic only to NCA (class II)
- Bacteria which are pathogenic only to humans (class III)
- Spoilage bacteria transmitted via passive transport (class IV)

The authors were cautious with the term "zoonosis" as it refers to a disease that is transmitted naturally from an animal to a human being. There is in fact another class of interaction which refers to zoonosis *in sensu stricto*, i.e. pathogens transmitted via active transport as practiced by haematophagous, parasitic, and other arthropods that transmit a variety of human diseases, (e.g. trypanosomiasis). However, these insect species are not consumed traditionally, which is why they are not considered in this review. Instead the authors rather refer to bacteria which appear in both NCA and humans, with different levels of pathogenicity, as a direct oral transmission from the arthropod to the human was rarely documented. This is probably due to the facts that a) the medical implications of traditional entomophagy have been poorly documented, and b) most NCA are consumed after further processing which usually includes heating, inactivating thus the majority of pathogenic microorganisms.

Bacterial diseases in NCA (classes I and II) frequently are characterized by bacteraemia, septicaemia, and toxaemia. Clinical signs in arththropods involve digestive symptomatology, and dead animals darken quickly, become soft and acquire a putrid odour. Some of these pathogens are responsible for economically important production diseases in honeybees and silkworms (e.g. *Paenibacillus larvae* or *Staphylococcus aureus*), others were studied because of their potential to control pests, especially moths (*Bacillus thuringiensis* or *Enterococcus faecalis*). While Table 1 sums up the bacteria found generically in "insects", Tables 2–7 detail findings divided into major taxa.

Most human pathogens may be transmitted by insects that act as passive vectors without truly affecting them (class III). Data on this subject can be gathered by reviewing the role of arthropods in modern livestock farming, food storage in general and in human health facilities. Pathogens are transmitted by means of the mechanical dislodgement from the exoskeleton (by attracting particles via electrostatic charges and/or adhesion to the body via the sticky