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The merits of entomophagy in the post COVID-19 world

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ABSTRACT

Background: In 2020, human society underwent several drastic changes due to the coronavirus disease 2019 (COVID-19) pandemic, which generated an unprecedented global impact. Since the onset of the COVID-19 pandemic, various pressing concerns underlying food security, such as transport, production, and maintenance of the supply chain, have been raised.

Scope and approach: The present study aimed to describe and review the merits of entomophagy in the post COVID-19 world, especially with regard to the low risk for zoonotic disease spread, high production rate, and future prospects for inducing entomophagy to enhance the diversity in the food system in comparison to conventional livestock.

Key findings and conclusions: The advantages of entomophagy in the post COVID-19 world have been elucidated herein, with particular emphasis on the minimal risk of zoonotic disease transmission and production efficiency, in addition to the future goal of establishment of entomophagy to expand redundancy and diversity in the food system as against the utility of conventional livestock. In the current scenario, as well as in the post COVID-19 situation, boosting entomophagy may play a pivotal role in global food security, as the aspects already touched upon have amply demonstrated.

1. Introduction

In 2020, human society was radically altered due to the coronavirus disease 2019 (COVID-19) pandemic, which led to serious consequences worldwide. COVID-19 was first recorded in Wuhan, China, and subsequently spread to all continents by April (Lau et al., 2020; Nicola et al., 2020). To retard the spread of COVID-19, China enforced a lockdown in Wuhan city on 23 January 2020 (Lau et al., 2020; Nicola et al., 2020). The lockdown was put in place to restrict human movement, and to significantly curb educational, political, and economic activities (Lau et al., 2020).

The COVID-19 pandemic has resulted in an imminent, serious, global human health emergency. Necessary measures against the virus, such as quarantines and infection-preservation controls, will be in place for several months more, with no certainty as to when the restrictions would be lifted. International efforts to control the spread of the virus by severely limiting travel will inevitably result in a severe economic and social downturn, which will impact the functioning of food systems around the world (Torero, 2020). The coronavirus pandemic has shed

light on a number of pertinent facts, the most evident being the interconnectedness of our world (Stephens, Martin, van Wijk, Timsina, & Snow, 2020). The impact of globalization is most obvious in the severely disrupted supply chains that threaten food security worldwide. Maintaining or reweaving these webs will involve technology, innovation, and political resolve (Stephens et al., 2020).

Since the emergence of the COVID-19 pandemic, various issues concerning food security, including transport, production, and supply chain preservation, have been raised (Stephens et al., 2020; Torero, 2020). The food system in post COVID-19 world have been considered for food industry and safety (e.g., Galanakis, 2020; Rizou, Galanakis, Aldawoud, & Galanakis, 2020). For example, Rowan and Galanakis (2020) suggested that COVID-19 pandemic provide us the challenges and opportunities for changing agri-food systems and green deal innovations. The focus of the present commentary is on concerns regarding conventional livestock production. For example, 1) apprehensions that COVID-19 and other infectious diseases could be transmitted and/or emerge via livestock–human interaction (Opriessnig & Huang, 2020; Murdoch & French, 2020) and 2) concerns that

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redundancy and diversity in food systems are insufficient for the development of resilience in the event of recovery from COVID-19 (Garnett, Doherty, & Heron, 2020).

Entomophagy, the consumption of edible insects, has been considered an alternative or additional source of animal proteins, which is an important macromolecule source for human (Galanakis, 2015). Over 1900 species have reportedly been utilized for entomophagy, and it is estimated that insects comprise a portion of the traditional diets of at least two billion people (van Huis et al., 2013). Despite historical references to the use of insects as food, topics based on entomophagy have begun to capture public attention worldwide only recently (FAO, 2012). The consumption of insects has emerged as a novel trend in food science from 2013 onward, when the Food and Agriculture Organization of the United Nations published a document entitled “Edible Insects: Future Perspectives of Food and Nutrition Security”. Numerous edible insects have been traditionally gathered from forest habitats; however, innovations in mass-rearing systems for insect larvae have been introduced and are already in use (Sanchez-Muros & Manzano-Agugliaro, 2014; Dennis & Oonincx, 2012). Insect farms are currently at the development stage and are beginning to create a completely unique agricultural sector.

Entomophagy potentially imparts redundancy and diversity to the food system, with reduced risk of infectious disease transmission, including COVID-19, and environmental impacts. Additionally, the development of entomophagy does not carry the risk of emergence of new zoonoses. In the present commentary, the merits of entomophagy in the post COVID-19 world have been discussed, especially with regard to the low risk for zoonotic disease transmission, elevated production rate, and future projections for the furthering of entomophagy to augment redundancy and diversity in the food system when evaluated against conventional livestock.

2. The role of entomophagy in food safety and the epidemiology of zoonoses

Although the role of arthropods in zoonotic transmission is undeniable, it is believed that edible insects pose a low risk of transmitting zoonotic diseases. This is because insects intended for human and animal nutrition are pests that feed on plant material or agricultural by-products. Therefore, these insects do not act directly as vectors of pathogens between humans and animals. Regarding entomophagy, a strong species barrier that prevents insect-specific pathogens from colonizing the human body is also important. In certain cases, even insects infected with various pathogens are consumed by humans (i.e., bee brood infested with *V. destructor* or moth larvae infected with *Ophiocordyceps sinensis*) (Cao, Ye, & Han, 2015; Evans et al., 2016). Insect breeding is of potential benefit in the context of infectious animal diseases such as African swine fever because it allows farmers to re-qualify from conventional animal breeding to insect livestock. This phenomenon would significantly diminish the odds of contracting new infectious diseases, including zoonoses, by reducing the number of conventional animals kept in agriculture and husbandry.

Although edible insect rearing is a safe alternative to conventional livestock husbandry, it should be emphasized that they are not free from pathogens. However, most insect-specific microorganisms do not pose a threat to humans and are not involved, to a significant degree, in the epidemiology of zoonoses.

2.1. Viruses

There are currently no prior studies on the pathogenicity of insect-specific viruses in humans (EFSA 2015; van der Fels-Klerx, Camenzuli, Belluco, Meijer, & Ricci, 2018; Dicke et al., 2020). For example, Baculoviridae (nosogenic for Hymenoptera or Diptera) are characterized as nonpathogenic and nontoxic to mammalian hosts (Paul, Hasan, Rodes, Sangaralingam, & Prakash, 2014). It is believed that the specificity of

insect viruses is mainly limited to the species taxon and they are unable to replicate in vertebrate cells. Due to the lack of analogous insect viruses in humans, there is a negligible risk of evolution of new mammalian-specific virus strains by recombination and reassortment leading to host switching, as was reported in the case of Swine flu. Regarding the COVID-19 pandemic, Dicke et al. (2020) concluded that the hazard of edible insects acting as a transmission vector of SARS-CoV-2 is extremely low. This is caused, for example, by a variant structure of the ACE2 receptor in insects (angiotensin-converting enzyme 2) utilized by SARS-CoV-2 (Dicke et al., 2020). This is a valuable example demonstrating that edible insects should not be a reservoir for viral diseases with epizootic potential. Although vertebrate pathogenic viruses cannot replicate in arthropods, these pathogens may still be transmitted passively by edible insects.

2.2. Bacteria

Symbiotic or entomopathogenic bacteria also pose a low epidemiological threat (Boemare, Laumond, & Mauleon, 1996; Lacey & Siegel, 2000; Kikuchi, 2009). An optimal example in this case is *Wolbachia* spp. (a bacterium pathogenic to mosquitoes). Although vertebrates have been exposed to this bacterium for thousands of years, no detrimental effects of this pathogen on animals other than arthropods have been reported so far. (Popovici et al., 2010). Moreover, numerous entomopathogenic bacteria are utilized in the agricultural sector as biological pest-control agents, and their safety has been well documented. Due to a multitude of insect species intended for consumption, a prominent diversity in the insect microbiota may be observed. Garofalo et al. (2017) discovered the presence of several gut-associated bacteria, some of which may act as opportunistic pathogens in humans. However, it should be noted that these opportunistic microorganisms were not insect specific. Moreover, there are no studies on the possible pathogenicity of symbiotic bacteria occurring in insects.

2.3. Fungi

In humans, candidiasis and dermatophytosis are among the most commonly diagnosed fungal diseases. Insect-specific pathogenic fungi are of limited importance in epidemiology as they have not been demonstrated to affect humans or animals. Insects infected with *Ophiocordyceps sinensis* have been consumed in Asia since the 15th century, although hazardous impacts on vertebrates have not been demonstrated (Fung, Lee, Tan, & Pailoor, 2017). In addition, *Beauveria* spp. and *Metarhizium* spp. utilized in pest management are considered to be safe; additionally, one case report of *Beauveria* spp. infection in a patient with immunosuppressive therapy was reported (Henke et al., 2002; Zimmermann 2007a, 2007b). Microsporidia may play a role in human epidemiology; however, this topic is currently neglected. Studies have shown that *Trachipleistophora* spp., probably an insect-origin microsporidian, can infect vertebrates (Vávra, Horák, Modrý, Lukeš, & Koudela, 2006; Vávra, Kamler, Modrý, & Koudela, 2011). In our opinion, the role of entomopathogenic fungi in the safety of insect-derived food products warrants further research.

2.4. Parasites

The group of pathogens that are currently at the greatest risk are parasites (Gałęcki & Sokół, 2019). Insects can serve as an intermediate host (i.e., cestodes); furthermore, even parasites pathogenic to insects can cause digestive tract disorders (*Gordius* spp.) or allergies (*Lophomonas blattarum*). Despite this fact, insect-specific parasites are unable to complete the full development cycle in vertebrates, which in practice limits their pathogenicity to single individuals. This also implies that further transmission between vertebrates is impossible. In terms of invasive diseases, it is important that insects play a role in the dispersion of the developmental forms of human and animal parasites in the

environment. Numerous studies have highlighted, for example, the role of insects in the transmission of protozoa such as *Cryptosporidium* spp. (Graczyk, Cranfield, Fayer, & Bixler, 1999; Gałęcki & Sokół, 2019). In terms of human and animal nutrition, it could be of significance to recognize the allergenicity of insect-specific parasite proteins, as they are likely to be consumed as part of the final edible product.

2.5. Allergenicity aspects

Allergenicity is one of the most important aspects of food safety in entomophagy. As with all foods, edible insects can be potentially allergenic. Currently, 239 allergens from arthropods have been registered in the Allergen Nomenclature Sub-Committee of the World Health Organization (de Gier & Verhoeckx, 2018). Significant insect-origin allergens including: hyaluronidase, phospholipase A, tropomyosin, arginine kinase, α -tubulin, β -tubulin, fructose-biphosphate aldolase, myosin light chain (Ribeiro, Cunha, Sousa-Pinto, & Fonseca, 2018). In total, 116 cases of allergic reactions following insect ingestion were described and most were caused by grasshoppers, locusts and lentil weevils (de Gier & Verhoeckx, 2018). Coleoptera, as the most frequently consumed insects (31% of all insects consumed) (van Huis et al., 2013), caused only 3 cases of allergy. Clinical cases after the ingestion of Isoptera, Odonata and Diptera have not been reported. The most common symptoms occurring after insect consumption include anaphylaxis, asthma dyspnea, erythema, gastrointestinal symptoms, hypotension, itching, tachycardia, urticaria and even fainting. People allergic to seafood are at special risk, as these allergens are present in both of these groups of products. In addition to food allergies, inhalation allergies may also occur, for example in crickets and cockroaches farm workers (Pener, 2016; Pomés, Mueller, Randall, Chapman, & Arruda, 2017). Insects, besides being a direct allergenic themselves, can also transmit allergens. Arthropods can be infected with mites and contaminated with their metabolites, which are a significant allergenic agent. Cockroaches may also carry *Lophomonas blattarum* or *Gregarina* spp., which may be involved in allergic reactions. Insect-specific parasite proteins can also be potentially allergenic. The use of bees in human nutrition can also expose people to pollen, which is an allergic factor for many people. In the case of keeping animals on grain, e.g. wheat, there is a risk of contamination of insects with gluten, which may be important for patients with celiac disease. Insect proteins allergenicity and potential of allergens transmission should be further investigated to ensure food safety.

3. The role of edible insects in the transmission of diseases

Most of the insect-specific pathogens mentioned do not represent a risk in the epidemiology of human and animal infectious diseases. At present, the pathogenicity of insect-specific viruses or bacteria in humans and human-/animal-specific viruses and bacteria in insects has not been proven. Nevertheless, edible insects can play a role in the transmission of pathogens, and insect-based products should be evaluated in terms of food safety. The risk factors will not be the same for the different product categories, because the transformation of insects includes procedures to reduce the microbiological load. Highly processed insect-based products are much safer from a biological safety point of view than raw or dried insects.

3.1. Vectors of pathogens

Another threat to entomophagy is the potential role of insects as biological and mechanical vectors of human and animal pathogens. Persistent risks may include *Escherichia coli*, *Salmonella* spp., *Staphylococcus* spp., and *Listeria monocytogenes*. Insects can also act as intermediate hosts or mechanical vectors for parasites, for example, protozoa or tapeworms. However, a similar phenomenon may occur in conventional livestock; therefore, with the application of Good Practice for Farm

Animal Breeding, biosecurity, and appropriate sanitary and veterinary regulations, this threat can be easily eliminated.

3.2. Breeding and technological processes

Even if edible insects may be potentially safe from a microbiological point of view, the technological processes of their acquisition and processing may affect the safety of the final product. If insect farm workers do not follow proper sanitary and biosecurity rules, they may also introduce pathogens potentially dangerous to humans. Because insects can act as mechanical vectors, this threat seems to be real. Moreover, due to the lack of biosecurity, insects may be exposed to microorganisms transmitted, for example, by flies or rats. Therefore, in our opinion, in insect breeding, similar legal regulations and veterinary controls should be introduced as they are applicable in conventional animal husbandry.

During the stages of transformation, such as drying, transportation, storage, and marketing, product contamination may occur due to failure to observe proper sanitary procedures or deviations from technological processes (e.g., high bioavailability of water in the final product). Moreover, safety measures should be implemented according to worker's medical conditions, personal hygiene, disinfection of surfaces, keeping working environment clean, food preparation and deliveries (Rizou et al., 2020). As with all nutritional products, these seems to be the most crucial food chains points in implementation "from farm to fork" idea in entomophagy. Therefore, insect-based products should be constantly monitored for biotic contamination. An important element of the insect production technology is obtaining a safe product for consumers, which can be ensured by the Hazard Analysis and Critical Control Points System (HACCP) quality control system.

4. Entomophagy epidemiological perspectives

Despite earlier information, little is known about the microbiological safety of edible insects. The risk of insect-specific pathogens adapting to new hosts is unpredictable and cannot be excluded. For example, insect-specific viruses are thought to be ancestral to arboviruses (Öhlund, Lundén, & Blomström, 2019), which cause West Nile fever or Dengue fever. This indicates that evolutionary processes gave rise to novel insect-origin pathogens. There is a probability that a similar phenomenon may occur in the future following the introduction of arthropods into the diet. Edible insects also possess a species-specific microbiome, and their impact on humans and animals has not been fully verified. Certain insect-specific microorganisms may act as opportunistic pathogens.

Conventional livestock and the related food supply chain require the involvement of many people who may be the potential source of infections (Rizou et al., 2020). Insect farming requires a small number of staff and may become automated in the future, which will significantly reduce the possibility of transmitting new pathogens. Our belief is that if appropriate legal regulations concerning breeding, processing, and production of edible insect products are developed and complied with, the implementation of ISO or HACCP standards, and including this sector under sanitary and veterinary monitoring, will mitigate the risk of pathogen transmission to a level below that prevalent in conventional farms. Edible insect-based products will not pose a greater threat than traditional food because possible pathogenic microorganisms that occur in both of these groups of products have a low epizootic potential; this may only cause local cases and could be related, for example, to the distribution of a batch of products. In our opinion, the development of insect farming for nutritional purposes does not harbor the risk of the emergence of a new pandemic, as was observed with COVID-19, Swine flu, or Avian influenza, which are closely associated with animal consumption or breeding.

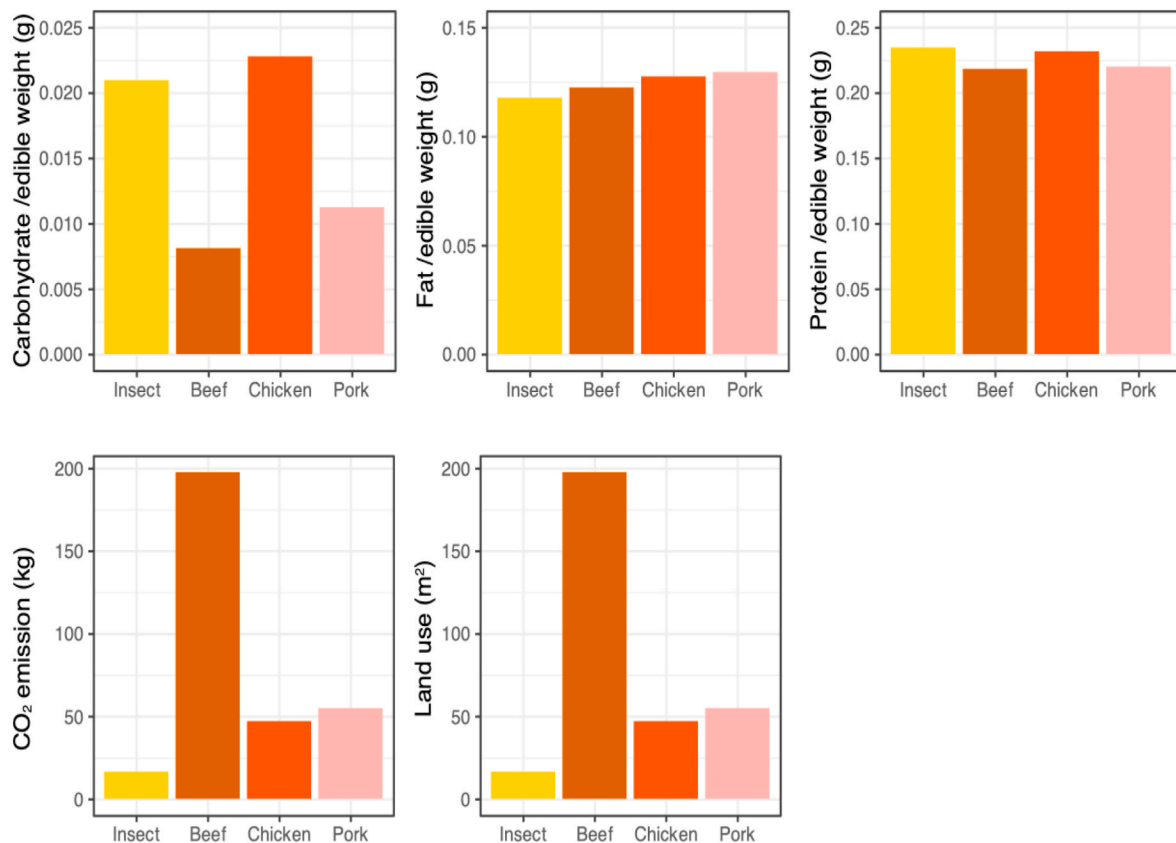


Fig. 1. Nutrients and environmental impacts of livestock. The mean nutrients contents (Source: [Mulia & Doi, 2019](#) for various insect species) and CO₂ emission potential and land use for the production (Source: [Ooninx & De Boer, 2012](#) for mealworm).

5. Environmental benefits of entomophagy

Entomophagy potentially provides redundancy and diversity in the food system along with higher nutrient contents (Fig. 1) and a higher production rate ([Collavo et al., 2005](#); [Mulia & Doi, 2019](#); [Berggren, Jansson, & Low, 2019](#)). The environmental benefits of entomophagy are attributed to the higher feed conversion efficiency and less land-dependent production compared to conventional livestock ([van Huis et al., 2013](#)). Entomophagy, therefore, contributes positively to the sustainability of human society and land use ([Mulia & Doi, 2019](#); [Berggren et al., 2019](#)).

The environmental benefits of rearing insects for food and feed are attributed to the high feed conversion efficiency of insects. Crickets, for example, require only 1.7 kg of feed for every 1 kg of their body weight to grow ([Collavo et al., 2005](#)). Insects are reported to emit fewer greenhouse gases than other livestock; they require significantly less land use than that necessary for other livestock (Fig. 1, [Dennis & Ooninx, 2012](#); [Ooninx & De Boer, 2012](#)). In addition, insects can be reared on organic side-streams (including human and animal waste), which could potentially increase the profitability of rearing them ([Veldkamp et al., 2012](#)). Therefore, entomophagy contributes positively to the environment as well as to the sustainability of human society and land use.

In the post-COVID19 world, the increasing world population could raise the risk of new outbreaks in densely populated areas. One way to counter this is to provide more land per person. This is the importance of efficient use of land in producing food, so that there is no risk of competition with land that can be employed for the construction of residential areas. Insect production has a higher feed conversion rate and less land use requirement compared with cattle rearing ([Dennis & Ooninx, 2012](#); [Mulia & Doi, 2019](#); [Berggren et al., 2019](#)). This is a merit in favour of boosting entomophagy instead of other livestock;

furthermore, entomophagy could serve as a viable alternative solution to land-use issues. While, some studies showed that Westerners' willingness to eat insect-containing food was low ([Jensen & Lieberoth, 2019](#)). Recent studies revealed that tasting and food system of entomophagy to the acceptance of entomophagy for the consumers ([Riggi, Veronesi, Goergen, MacFarlane, & Verspoor, 2016](#); [Jensen & Lieberoth, 2019](#); [Batat & Peter, 2020](#); [Tuccillo, Marino, & Torri, 2020](#)). [Jensen and Lieberoth \(2019\)](#) found that social norms play a substantial role in Westerners' (un)willingness to eat insects and pointed to avenues for harnessing social norms in marketing efforts.

Currently, there are several factors contributing to heightened food insecurity. These include population expansion, global warming, the use of food resources as biofuels, natural disasters, and armed conflict. This was described by Jose Graziano da Silva, in a report drafted for the FAO'. In this context, edible insects are increasingly being used as an alternative food source. Their roles are multifaceted and contradictory, ranging from harmful impacts on human and animal health and agriculture, to their significance in ecosystems, plant reproduction, soil fertility, and the maintenance of biological balance.

6. Nutritional perspective

The role of insects is now being evaluated for the nutritional value they can provide as a source of food, especially in terms of their protein content (which is of immense biological value) (da Silva Lucas et al. 2020, Fig. 1). Other nutritional factors include lipids (essential fatty acids comprising an important component) (Fig. 1), vitamins, minerals, etc... The rapidly growing edible insect industry produces protein bars, pasta, and chips manufactured from insect-derived products ([FAO, 2012](#); [Nongonierma & FitzGerald, 2017](#)). Despite the fact that the process of transformation improves the acceptancy of insect by consumer, technological processes itself involved several steps to decrease the

microbiological load and improve the food safety. High digestibility values have been recorded in case of edible insects, however the presence of chitin may cause reduction in nutrient digestibility (Gasco et al., 2019). The insect species and technological processing may also influence digestibility (Gasco et al., 2019). Given the growing market demand for edible insects and the inclusion of this new source as a food product, it is crucial that several parameters are assessed in-depth from a food safety perspective.

7. Conclusions

In the present commentary, the merits of entomophagy in the post COVID-19 world have been reviewed, particularly with regard to their low risk for zoonotic disease transmission and high industrial output, as well as future prospects for inducing entomophagy to raise the degree of redundancy and diversity in the food system as opposed to the application of conventional livestock. There are several commentaries related to the post food system and production under/after COVID-19 pandemic (Galanakis, 2020; Rizou et al., 2020), and these commentaries also suggested this is a change to challenge for rebuilding local/global food systems. We also highlighted the novel challenges in entomophagy, including epidemiological safety of insect breeding and insect-based products.

The pandemic presents an opportunity to hit the reset button to configure the contributing factors in an ideal fashion (Torero, 2020), with scientists playing an important part. Under the current situation and post COVID-19 scenario worldwide, boosting entomophagy may play an important role in global food security, as the merits that have been highlighted in the above-mentioned sections have demonstrated.

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Declaration of competing interest

Authors declare no conflict of interest.

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