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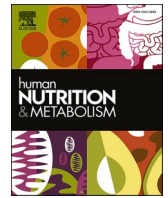
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Proteins from insects: A sustainable alternative for oral health within the one health concept and the planetary health diet

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ABSTRACT

The growing use of insect-derived proteins as a food source, driven by their nutritional benefits and low environmental impact, raises questions about their impact on human health, particularly oral health. This position paper analyzes the potential implications of integrating insect proteins into the diet, with a special focus on dental, periodontal, and oral microbiome health. By offering complete amino acid profiles, omega-3 fatty acids, and antimicrobial peptides, insect proteins may help address nutritional gaps and positively influence oral tissue regeneration and microbiome balance. Their low-carbohydrate content also reduces substrate availability for cariogenic bacteria, making them a valuable alternative to starch- or sugar-rich diets. We justify this dietary transition in light of present nutritional deficiencies and demonstrate how insect proteins can register within a holistic approach to global health (*One Health*) and the *Planetary Health Diet*, supporting sustainability and improving overall health. However, further studies are needed to evaluate their safety as potential sources of allergens and contaminants. Both in-vitro and in-vivo studies are needed to assess correlations with the oral microbiota and its most frequent dysbiosis-related manifestations.

1. Introduction

Dental caries, one of the most common non-communicable diseases worldwide, is influenced by a variety of factors, including eating habits and oral hygiene [1]. The move towards more sustainable diets has highlighted the need to find new protein sources that not only meet nutritional requirements but also contribute to reducing the environmental impact of human diets. The recent shift from interpreting dental caries as an infectious, communicable disease caused by *S. mutans* to understanding it as the result of an "ecological catastrophe" is due to the study of the human microbiota [2].

In this context, the development of dental caries can be attributed to alterations in the equilibrium of the resident oral microbiota, characterized by a reduction in diversity and an increase in the prevalence of specific components that thrive in an acidic environment. The main driver of this dysbiotic shift is frequent exposure to sugars, in addition to decreased salivary flow and lack of daily oral biofilm disruption [1,3,4]. Processed sugar- and starch-containing foods are consistently associated

with greater caries experience among individuals [5]. Starches from wheat-based grains are a principal component of the human diet and are found in a wide range of processed foods, thus forming 40–75 % of total dietary intake in Western diets [6,7]. Thus, it would be beneficial to explore alternative dietary strategies that involve a reduction in carbohydrates.

The *Planetary Health Diet*, a dietary framework developed by the EAT-Lancet commission [8], proposes a diet designed to feed the world's population healthily while respecting the planet's ecological limits. This concept emphasizes a diet rich in plant-based products, with moderate consumption of animal-based foods, to reduce carbon footprints and promote sustainability [8]. Insect proteins, with their complete nutritional profile and low-impact production, fit perfectly into this approach [9]. Compared to traditional livestock farming, insect farming requires significantly fewer resources such as feed, water, and land, while producing fewer greenhouse gas emissions [10]. So, crickets can convert 1.7 kg of feed into 1 kg of edible protein, compared to 8 kg of feed for the same output of beef protein [11]. This efficiency aligns insect farming

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with global sustainability goals and food security strategies.

Programs have been developed. For instance, the New Nordic Diet in Scandinavia focuses on local, seasonal, and plant-forward ingredients, reducing carbon emissions while improving health outcomes [12]. Similarly, insect farming in Southeast Asia has demonstrated how low-resource protein sources can simultaneously support livelihoods and address nutritional deficiencies [13–15].

By integrating these proteins into diets, we support not only better health but also a sustainable approach in line with the principles of the *One Health* concept and the *Planetary HealthDiet*. From a health perspective, insect proteins may offer specific benefits for oral health through their bioactive compounds, including antimicrobial peptides that can modulate the oral microbiome [16,17]. Moreover, their omega-3 content can reduce gingival inflammation [18,19], and their complete amino acid profile supports tissue regeneration and immune function [20–22].

However, despite the potential benefits of insect proteins, their impact on oral and systemic health has yet to be fully explored. Few studies to date have evaluated the specific effects of insect-derived nutrients on oral microbiota balance or the prevention of dental diseases, highlighting a critical research gap. This position paper aims to fill this gap by examining how insect proteins might address present nutritional deficiencies in traditional diets, with special reference to dental health, periodontal health, and the oral microbiome.

The data presented in this manuscript is based on a theoretical framework supported by a critical analysis of existing literature. As a position paper, it aims to synthesize current knowledge and provide a conceptual foundation for future research in this emerging field. Given the lack of specific studies directly investigating the correlations between insect-derived proteins and oral health outcomes, this manuscript draws upon evidence from related fields to investigate the prospective role of insect proteins in promoting oral and systemic health. The novelty of this topic underscores its pioneering nature and the necessity for further empirical studies to validate these initial hypotheses.

Despite the potential benefits of insect proteins, their impact on oral and systemic health remains underexplored. To date, few studies have specifically investigated the effects of insect-derived nutrients on oral microbiota balance or the prevention of dental diseases, highlighting a critical research gap. This position paper seeks to address this gap by synthesizing current knowledge and proposing a conceptual framework for future research.

Drawing on evidence from related fields, this manuscript explores how insect proteins could contribute to oral and systemic health, particularly in addressing nutritional deficiencies in traditional diets. By examining their potential implications for dental health, periodontal health, and the oral microbiome, this paper underscores the pioneering nature of this topic and the urgent need for empirical studies to validate these initial hypotheses.

2. Discussion

2.1. Nutritional challenges in dental health

Modern diets are often characterized by excessive consumption of fermentable carbohydrates, particularly refined sugars and processed starches, which play a central role in the pathogenesis of dental caries [6,7]. When these carbohydrates are consumed, cariogenic bacteria such as *Streptococcus mutans* and *Lactobacillus* metabolize these sugars into organic acids, mainly lactic acid, via glycolytic fermentation. Processed foods' gelatinized starches are rapidly hydrolyzed by oral amylases into small polysaccharide fragments [6]. Starch-containing food particles trapped on the tooth surface become an optimal substrate for sugar accumulation and thus for bacterial acid production, resulting in a local pH drop and the onset of the enamel demineralization process [23]. Human exposure to foods produced through high-temperature cooking of refined sugar and starch suspensions causes greater biofilm-induced

acidogenesis [23]. Flour starches have very high acidogenicity [23, 24], and the combination of starch and sucrose is associated with the greatest mineral loss of tooth hard tissues [24].

In contrast, insect-based flours contain significantly lower amounts of fermentable carbohydrates, thereby reducing the substrate available for bacterial acidogenesis. This makes them a potentially valuable dietary alternative for caries prevention. Moreover, insect proteins offer a rich source of essential amino acids and micronutrients that directly support oral tissue health, including calcium, zinc, and vitamin D [25, 26].

Compared to insect-based proteins, staple plant-based protein sources such as grains (e.g., wheat, rice, and corn) are often deficient in essential amino acids like lysine and methionine [27,28]. For instance, wheat protein contains approximately 2.6 g of lysine per 100 g of protein, which is far below the 5.5–6.8 g found in cricket flour [29]. Similarly, legumes such as lentils and chickpeas, while rich in protein, lack sufficient methionine, which insect proteins supply in significant quantities [30]. These deficiencies can impair oral tissue repair and immune responses, particularly in diets lacking diverse protein sources.

On the other hand, insect proteins, approved for human consumption by the European Union in 2023, have shown significant promise [31]. The introduction of insects as an additional food source or component of the Western diet is being seriously considered as a response to global nutritional and environmental challenges [32]. More than two billion people worldwide rely on insects for nourishment, with regions such as Southeast Asia and Africa leading in cultural and dietary integration of insect proteins [33]. However, incorporating insects into Western diets necessitates addressing cultural adaptability and consumer acceptance. This could be facilitated through the gradual introduction of processed forms, such as flours or protein bars, which are more familiar to Western consumers [33].

2.2. Justifying the purpose for insect proteins within the planetary health diet

a) Responding to crucial amino acid deficiencies

Insect proteins provide a complete amino acid profile, offering a significant advantage over many western diet food sources that typically lack essential amino acids, such as lysine and methionine [34]. Cricket flour is rich in lysine, an essential amino acid for collagen synthesis, which is vital for the structural integrity of skin, bone, dentin, and gingival tissues [35,36]. Lysine is essential for collagen cross-linking through lysyl oxidase, enhancing its resistance to degradation. Sufficient lysine intake supports gingival strength, elasticity, and connective tissue repair following injury or surgery. By comparison, staple foods such as cereals (e.g., wheat and corn) are deficient in lysine, while legumes such as lentils lack sufficient methionine [37,38]. This makes insect proteins uniquely positioned to address these deficiencies, particularly in populations dependent on plant-based diets.

Insect proteins supply essential amino acids, including methionine, a precursor to cysteine and taurine [39]. Cysteine is vital for glutathione synthesis, a key antioxidant that protects against oxidative stress in periodontal tissues [40]. Taurine offers anti-inflammatory and osmoregulatory benefits for periodontal health [41]. By enhancing the intake of these amino acids, insect proteins can address nutritional deficiencies in contemporary diets, support oral tissue regeneration, and aid in the prevention of tissue degradation-related diseases.

b) Make up for deficiencies in beneficial lipids

Insects are not only rich in essential amino acids but also a valuable source of polyunsaturated fatty acids, particularly omega-3s (EPA and DHA), which play a key role in modulating inflammation [42–45]. Unlike pro-inflammatory saturated fats, omega-3s are precursors to anti-inflammatory mediators such as resolvins, protectins, and maresins.

They also inhibit osteoclast activity via the RANKL/NF- κ B pathway, helping to prevent alveolar bone loss, a common complication of periodontitis [46]. Insect-derived lipids, especially phospholipids, enhance the bioavailability of polyunsaturated fatty acids, promoting their integration into cell membranes [42–45]. This is crucial for maintaining membrane integrity in tissues like the gingival mucosa, which endure constant mechanical and microbial stress [47].

c) Rebalancing the oral microbiome

The oral microbiome, comprising over 700 bacterial species, fungi, viruses, and protozoa, plays a vital role in oral health by regulating pathogen colonization and aiding digestion [48]. Dysbiosis, an imbalance favoring pathogenic bacteria, is linked to conditions like caries, gingivitis, and periodontitis [49].

The balanced composition of insect flours, rich in both macronutrients and micronutrients, can support the equilibrium of the oral microbiota. The supply of omega-3 fatty acids, along with micronutrients such as zinc and iron, may promote anti-inflammatory activity and be beneficial in dietary regimens for age groups particularly vulnerable to nutritional deficiencies [42–45]. While further research is required, existing evidence on omega-3s and antimicrobial peptides suggests that insect proteins could be a promising tool for managing dysbiosis and supporting both oral and systemic health.

While the environmental benefits of insect proteins are well-discussed, their implications for oral health are equally significant. Insect-derived proteins can provide essential nutrients such as lysine, methionine, and omega-3 fatty acids, which are critical for maintaining oral tissue integrity, reducing gingival inflammation, and promoting collagen synthesis for periodontal repair [35,36,41].

Moreover, bioactive peptides and antimicrobial compounds found in insect proteins have shown potential to modulate the oral microbiome, limiting the growth of cariogenic bacteria like *Streptococcus mutans* and promoting the proliferation of commensal species [16,29,50]. By supporting a balanced microbiome, insect proteins may reduce the incidence of dysbiosis-related conditions such as dental caries and periodontal disease.

Studies have demonstrated that diets enriched with antimicrobial peptides (AMPs), such as defensins and cecropins found in insect proteins, can inhibit the adhesion of pathogenic bacteria to oral tissues while fostering the growth of beneficial microbiota [16]. These combined mechanisms highlight the potential for insect proteins to be integrated into dietary strategies aimed at improving oral and periodontal health.

2.3. Alignment with European recommendations, the "Planetary Health Diet" and the "One Health" concept

The European Union and the EAT-Lancet commission suggest reducing animal protein consumption in favor of more sustainable sources, as proposed by the *Planetary Health Diet* [8]. This transition is motivated by the negative environmental impacts linked to intensive livestock farming, including deforestation, excessive water consumption, and greenhouse gas emissions [32]. The *One Health* concept, which recognizes the interconnection between human, animal, and environmental health, supports this transition to alternative protein sources [51].

Integrating these examples highlights insects as a sustainable and eco-friendly protein source. Insects require significantly fewer resources than traditional animal proteins [32]. For instance, producing 1 kg of cricket protein requires around 2 kg of feed and 1 L of water, compared to 25 kg of feed and 15,000 L of water for the same amount of beef protein [52]. Additionally, insect farming generates up to 80 % fewer greenhouse gases and uses far less land, allowing up to 100 times more protein to be produced compared to cattle farming, with minimal impact on biodiversity [53].

In addition to their environmental benefits, insect proteins can improve oral health outcomes through their bioactive peptides, omega-3 fatty acids, and complete amino acid profiles. For example, omega-3s contribute to reducing alveolar bone loss by modulating the NF- κ B pathway, while lysine and methionine enhance the synthesis of periodontal collagen and connective tissue [21,54,55]. Furthermore, studies have shown that high-quality protein intake can improve wound healing in gingival tissues, reinforcing the role of insect-based proteins in maintaining periodontal health [56].

By reducing the availability of fermentable carbohydrates, insect flours may also decrease the acidogenic potential of oral biofilms, mitigating the risk of enamel demineralization. This dual benefit—antimicrobial activity and reduced cariogenic substrate—positions insect proteins as a unique dietary solution for preventing both dental caries and periodontal inflammation.

However, it is important to note that while preliminary data support the antimicrobial and anti-inflammatory properties of bioactive compounds found in insect proteins, large-scale clinical studies specifically assessing their impact on the human oral microbiome are lacking. In vitro and animal model studies have provided valuable insights, but more robust, empirical evidence is needed to confirm these benefits in human populations [16,57]. Addressing this research gap will be critical for fully understanding the role of insect proteins in modulating the oral microbiome and improving dental and periodontal health outcomes.

So, insect proteins represent an innovative and environmentally sustainable food source that simultaneously addresses critical nutritional gaps and supports oral health. By contributing to the reduction of cariogenic substrates, strengthening gingival tissues, and promoting a balanced microbiome, insect proteins offer a unique opportunity to integrate sustainable dietary practices into preventive oral healthcare strategies.

2.4. Potential risks and research directions for safe integration of insect proteins

The European Food Safety Authority (EFSA) has emphasized that the levels of contaminants in insects or insect-based foods depend on factors such as rearing substrates, production methods and harvesting stages [58]. The introduction of insect flour-based products, which concentrate insect components, poses an additional safety concern. Unlike the traditional consumption of whole fried or grilled insects, flours may lead to a higher intake of potential allergens and contaminants, heightening the risk of unforeseen public health effects.

Insects have the potential to act as vectors for microorganisms such as bacteria, viruses, and parasites, which could pose health risks to consumers [59,60]. Furthermore, components derived from insects, such as chitin or 27-kDa glycoprotein, may provoke allergic reactions [34]. Moreover, insects may accumulate various contaminants, including mycotoxins, pesticides, heavy metals, organochlorine compounds, and dioxins, because of their exposure to rearing substrates or environmental conditions [61,62]. Additionally, certain insect species have been observed consuming plastic polymers, with degraded plastic residues detected in their frass through infrared spectroscopy [63]. Incorporating insects into the human diet entails potential risks that demand thorough investigation. While the specific implications for human health remain uncertain, these findings underscore the need for caution.

3. Conclusion

Insect-derived proteins represent a compelling opportunity to address global health, environmental sustainability, and nutritional challenges. By offering a complete amino acid profile, essential micronutrients, and anti-inflammatory omega-3 fatty acids, insect proteins can contribute to improved oral and periodontal health outcomes while supporting broader planetary health goals. Their low environmental

impact and efficient production make them an ideal alternative to traditional animal proteins.

To advance the integration of insect proteins into dietary recommendations, further research is needed to substantiate their effects on the human oral microbiome, dental caries prevention, and periodontal health through large-scale clinical trials. Researchers should focus on identifying the mechanisms of action for bioactive peptides and validating their antimicrobial and anti-inflammatory benefits.

Policymakers must support initiatives promoting insect protein production, such as economic incentives, regulatory frameworks for safety and quality control, and public health campaigns to improve consumer acceptance. Industry stakeholders are encouraged to develop innovative, palatable, and accessible insect-based products that align with nutritional and environmental goals.

Concrete public health policies should prioritize integrating insect proteins into school nutrition programs, dental health initiatives, and preventive care guidelines. Such policies will not only address existing nutritional deficiencies but also contribute to reducing the burden of oral diseases globally, while promoting sustainable food systems.

In conclusion, insect proteins provide a unique opportunity to bridge the gap between environmental sustainability and preventive healthcare. Collaboration among researchers, policymakers, and industry leaders is essential to harness the full potential of this novel food source for improving both global and oral health outcomes.

Authors' contributions

Conceptualization, M.M.; methodology, M.M. and D.B.; validation, M.J.; formal analysis F.C.; investigation M.J. and F.C.; data curation, A. N.; writing—original draft preparation, M.J. and I.D.I.; writing—review and editing M.M., L.O., D.B.; funding acquisition D.B.; visualization, I. DI; supervision, M.M.; project administration, M.M. and L.O. All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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