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Review paper

Edible insects as a source of dietary protein for companion animals with food responsive enteropathies – perspectives and possibilities

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Abstract

The incidence of chronic enteropathies (CE), in particular food-responsive enteropathies (FRE) in dogs, is on the rise in veterinary practice. The symptoms of these digestive disorders cannot be alleviated with the use of commercial hypoallergenic feeds. The applicability of novel materials in hypoallergenic dog feeds is limited, and edible insects could pose a viable alternative. Insects have a high nutritional value, and their potential can be harnessed to design personalized nutrition strategies. However, the use of insects in animal feeds should be rigorously tested. The aim of this study was to analyze the applicability of edible insects as a source of dietary protein for companion animals, including the current and future prospects. Canine food formulas should be evaluated in a clinical setting. The role edible insects in pet diets and the efficacy of this material in animal nutrition should be examined in advanced clinical trials in gastroenterology, histology, immunology, and microbiology. These efforts are required to guarantee the safety and efficacy of innovative insect-based feeds and to increase their popularity among veterinary practitioners, pet food producers, and animal owners.

Keywords: chronic enteropathies (CE), edible insects, edible insect industry, food-responsive enteropathies (FRE), veterinary diets, veterinary medicine



Introduction

Companion animals represent a significant proportion of veterinary patients. The European pet food market is valued at EUR 21 billion (Fediaf 2021), and the value of products and services for companion animals has been estimated at EUR 19 billion. The pet food industry has been growing at an annual rate of 2.6%. In Europe, the population of companion animals is estimated at 199 922 236, including 89 826 097 dogs and 110 096 139 cats (Fediaf 2021). Food formulas involving insects should be developed and thoroughly tested to evaluate the applicability of edible insects in pet nutrition. To overcome cultural and economic barriers, insect-based ingredients in feeds should not only have a high nutritional value, but should also deliver additional benefits such as hypoallergenic effects that have been reliably confirmed by clinical research on target species. Statistical and veterinary data suggest that the incidence of chronic enteropathies (CE) including food-responsive enteropathies (FRE) is considered as a frequent cause of presentation to the veterinarian (Chesney 2001, Dandrieux and Mansfield 2019, Makielski et al. 2019), possibly to a deterioration in the quality of commercial feeds, or developing better diagnostic methods. Edible insects have recently emerged as one of the most innovative dietary material in human and animal nutrition (Rumpold and Schlüter 2013, Patel et al. 2019). According to many researchers, the “six-legged livestock” constitutes a milestone in the diversification of protein sources and contributes to global food security (Kinyuru and Ndung’u 2019). The use of insect protein in pet nutrition should be evaluated in extensive clinical trials. Insects from sustainable farming systems are particularly desirable in the production of innovative feeds. Insect-based pet food fulfills the requirements for three out of the five types of innovations distinguished by Schumpeter (2017): a new good, a new market, and a new source of supply of raw materials. Innovative food formulas incorporating insect protein can be developed for use in the veterinary sector. These solutions can be applied in veterinary practice to design therapeutic diets for companion animals. However, novel feed ingredients have to be rigorously tested to determine their efficacy and safety. Feeds containing insect protein offer a particularly interesting alternative for veterinary medicine. In Europe currently, it has been proposed that all insects recognized as “Novel Food” could be included as a component of pet food (Regulation (EU) 2015/2283 of the European Parliament and of the Council of 25 November 2015, (Żuk-Golaszewska et al. 2022). These include: Black Soldier fly (*Hermetia illucens*), House cricket (*Acheta domesticus*), House fly (*Musca domestica*),

Jamaican field cricket (*Gryllus assimilis*), Lesser mealworm beetle (*Alphitobius diaperinus*), Locust (*Locusta migratoria*), Tropical house cricket (*Gryllobates sigillatus*) and Yellow mealworm beetle (*Tenebrio molitor*). Currently, the first two species are most commonly used (Kröger et al. 2020, Abd El-Wahab et al. 2021, Areerat et al. 2021).

Positioning of edible insects in the European pet food market

Around 38% of European households own companion animals, where 24% of pet owners have at least one dog, and 25% of households own at least one cat (Fediaf 2021). Due to social changes, cats and dogs are presently considered family members, rather than property (Hankin 2007, Forbes et al. 2018). Most dog and cat owners claim that their pets are integral members of their families (McConnell et al. 2019, White 2023). These changes are particularly evident in households run by Millennials (Generation Y) who largely drive the growth of the pet food market (Lincoln 2018, Forbes et al. 2018, Kucharska and Malinowska 2019). Approximately 82% of the surveyed Millennials claimed that pet ownership should come before parenthood because it better prepares them for starting a family (Oakland 2019, Graham et al. 2019). Pets are anthropomorphized by 42% of Generation Y owners (Ypulse 2020). This demographic group is also more susceptible to social changes, such as the COVID-19 pandemic which increased the demand for pet products (White 2023). Around 7% of Millennials and 26% of Generation Z have adopted a pet during the COVID-19 pandemic (Ypulse 2020, Beck et al. 2023). Millennials also spend more on pet food than any other generation. In 2020, 49% of Millennials purchased special food treats, and 30% bought high-end pet food over six months (Ypulse 2020). Only 9% of the respondents admitted to buying poor-quality pet food (Ypulse 2020). In Millennial-run households, spending on dogs increased 3.5-fold during the pandemic, which clearly indicates that Generation Y is the target market for insect-based pet food. Generations Y and Z have a greater interest in edible insects than other consumers (Dagevos 2021, Souilhac et al. 2021), which is another important consideration. Research has demonstrated that the acceptance of entomophagy is much higher in these generations (Taylor 2019, Fasanelli 2020). This observation can exert a synergistic effect on the use of edible insects in dog nutrition. The above generations are characterized by the highest levels of consumer innovativeness (Formica 2013) and are likely to spend more on innovative products (Drucker 2014).

Insect-based feeds may also attract the interest of consumers whose pets suffer from FRE. Currently, it is difficult to determine the exact prevalence of FRE in dogs. According to estimates, 17-48% of dogs are allergic to at least one food ingredient (Harvey 1993, Paterson 1995, Chesney 2001), which suggests that approximately 34 million of dogs in Europe could benefit from insect-based nutrition. However, these calculations are hypothetical because Dandrieux and Mansfield (2019) indicate that there is currently a lack of studies to determine the true prevalence of CE either at the level of general practice or referral. Pet owners are becoming increasingly aware that commercial pet food is not highly effective in alleviating the symptoms of FRE, which prompts them to search for innovative solutions with the assistance of veterinary practitioners. According to Woodmansey (2018), the demand for hypoallergenic dog food has increased by around 75% since 2016. The popularity of premium, light, and prescription pet food is on the rise (Euromonitor 2019). Insect-based food can cater to this demand. Innovative solutions have also attracted the interest of pet food manufacturers who have recognized the potential of edible insects in pet nutrition (Gałęcki et al. 2021, Valdes et al. 2022). Market research has demonstrated that a growing number of pet food producers show an interest in edible insects (Bae et al. 2020, Kępińska-Pacelik and Biel 2022).

The popularity of the proposed solutions is likely to increase in the insect industry. Current trends in agriculture indicate that insect farming will evolve into a novel segment of the farming industry (Gałęcki et al. 2021). Edible insects should be promoted as a viable alternative in the pet food sector to promote the development of a dedicated insect market and generate stable revenues for the new sector. Insect-based pet food is also likely to attract the interest of veterinary practitioners whose opinions on innovative nutritional solutions tend to be disregarded. Veterinarians could have an interest in the results of research evaluating the therapeutic efficacy of insect-based food and the implementation of pet food formulas addressed specifically to companion animals suffering from certain pathological conditions (Bosch and Swanson 2021, Lee et al. 2021). According to the available information, none of the currently marketed brands of insect-based pet food has been clinically approved.

Potential risks associated with insect-based pet food

There are many potential risks that could impede the implementation of pet food containing insect

protein (Lange and Nakamura 2021, Van Huis 2022, Gałęcki et al. 2023). One of the most obvious dangers is that similar products could be formulated and developed by competitors (Hill 1997, Smith 2011). Based on market observations, this risk has been evaluated as moderately high. The relevant threat could be minimized by developing transparent pricing policies, and/or introducing new marketing methods, and/or modifying food formulas in response to competitors' actions. Dishonest competition (Wolf 1937, Suleman 2011), in particular efforts to discredit insect-based pet food, poses yet another threat. This risk can be regarded as high due to the potential conflict of interest. Companies manufacturing insect-based pet food can minimize the threat of disinformation and dishonest competition by providing consumers with reliable information about their products. The risk associated with dishonest competition can be mitigated through effective PR and marketing campaigns, aimed at validating the rationality of the use of insects and presenting the added value in accordance with the assumptions of evidence-based medicine.

Legal and administrative risks (Żuk-Gołaszewska et al. 2022) relating to sanitary and veterinary requirements for insect-based pet food have been evaluated as low. The laws governing the use of edible insects in food and feed are being gradually relaxed. However, to avoid legal and administrative violations, pet food producers should carefully analyze the applicable regulations before developing insect-based foods and placing them on the market. Legal provisions and sanitary requirements (Lähteenmäki-Uutela et al. 2021) regarding pet foods containing insects can change over time, but this risk has been evaluated as moderately low. To avoid such violations, manufacturers should regularly monitor legislative changes and industrial standards to ensure that pet food parameters are consistent with the regulations. Pet food manufacturers should comply with legal amendments and adapt their formulas and production lines accordingly, to the extent that is technically and financially feasible. Intellectual property protection poses yet another risk (Boldrin and Levine 2002). This threat can be regarded as moderate, but its significance could increase in the future. Counterfeit products could be placed on the market as insect-based pet foods become more popular and widely available. To avoid the legal risks associated with intellectual property infringement, the results of research and development, including the developed formulas, should be adequately protected. Companies producing insect-based pet foods should monitor technological progress on the market to mitigate the relevant risks. The following risk is closely associated with consumer innovativeness (Barrena and Sanchez 2013, Siddiqui

et al. 2022). The specificity of the target market, consumer preferences, the extent to which a given product meets market needs (Bloch 1995, Van Kleef et al. 2005), and the palatability of pet food (Aldrich and Koppel 2015) are the main concerns in this group of threats. The relevant risks have been evaluated as moderate. Representatives of potential target groups should be invited to participate in the development and implementation of innovative pet foods to minimize this risk. Pet owners' opinions should be considered in the process of formulating innovative products. Valuable information can be also obtained from veterinary professionals (Kulkov et al. 2021). This risk can be minimized by analyzing the causes of product failure, and the identified issues should be urgently resolved.

Some consumers may find it difficult to accept insect-based foods (Deroy et al. 2015, Mancini et al, 2019). The risk of neophobia and negative attitudes towards entomophagy are regarded as moderately high. To overcome these problems, the formulated pet foods should be characterized by very high quality, and their therapeutic properties should be backed by research. Pet foods with scientifically proven benefits are likely to mitigate negative attitudes towards innovative products for companion animals. This risk can be mitigated through marketing and educational activities, including effective communication campaigns to provide consumers with reliable information about the benefits and safety of insect-based foods, and to reduce susceptibility to disinformation. Technological problems can also undermine the popularity of insect-based pet food. There is a risk that the claims for hypoallergenic products are not substantiated (Olivry and Bizikova 2010, Jeronim 2018). This risk can be regarded as moderately high because few innovative pet formulations have been clinically tested. Moreover, production lines in pet food plants may require certain modifications to process insect protein (Ortiz et al. 2016, Dossey et al. 2016, Ojha et al. 2021, Sindermann et al. 2021). Pet food producers work with similar materials, and this risk has been evaluated as moderate. Insect-based materials are abundant in fat and chitin, and they may not be adequately processed by conventional production lines. Therefore, to minimize this potential risks, a plant's ability to process insects into food should be checked before launching production.

Qualitative defects in insect materials pose an equally important problem (EFSA 2015, Murefu et al. 2019, Gałęcki et al. 2023). This risk should be evaluated as moderately high because the nutrient composition and nutritional value of pet food materials, in particular insect-based materials, can vary. Pet food manufacturers should work only with reliable suppliers, and all ingredients should be thoroughly checked before

they reach the production process. The causes of qualitative defects should be identified, and the appropriate remedy measures should be implemented, for example by improving storage conditions, eliminating defects and defective material batches, or changing suppliers.

Discussion

Many consumers have equally negative attitudes towards insect-based foods for humans and companion animals (Bakuła and Gałęcki 2021). Animal species of the family Canidae can be considered facultative insectivores (Sheldon 2013, Kępińska-Pacelik and Biel 2022). Insects were not a major food source in the diets of ancient dogs, but entomophagy is observed in wolves and foxes (Bueno and Motta-Junior 2004, Sheldon 2013). According to veterinarians, the incidence of FRE is on the rise in companion animals (Kawano et al. 2016, Dandrieux and Mansfield 2019). Insects are a rich source of protein (Hong et al. 2020), and their potential can be harnessed to design personalized nutrition strategies. There is evidence to indicate that insect protein can enhance immune functions (Gasco et al. 2021). The presence of chitin in insect meals has been also found to reduce *Escherichia coli* and *Salmonella* spp. counts (Islam and Yang 2017), which suggests that insect-based food can limit the use of antibiotics in the treatment of CE. According to research, edible insects are also effective in modulating gut microbiota in animals (Stull et al. 2018, Panteli et al. 2021).

The available brands of insect-based pet food are based on a limited number of insect species, including *H. illucens* and *A. domesticus*, whereas other insects are less widely utilized in the pet food industry. Other insect species are less popular because they grow at a slower rate and their production generates smaller profits. Diet plays a very important role in the treatment of many medical conditions (Tolbert et al. 2022). Insects are frequently incorporated into premium foods for animals with specialist dietary requirements, including allergic reactions to conventional protein sources. This fits into the general trend on the dog food market (Euromonitor 2019, Valdes et al. 2022).

Due to the growing popularity of edible insects, insect farming is likely to evolve into a novel agricultural sector (Van Huis 2020), which implies that a market capable of meeting future demand for insect protein has to be created (Gałęcki et al. 2021). New pet food brands based on insect protein are likely to be introduced in the near future. Insect-based foods also offer a viable alternative to conventional meat-based products (Gallen et al. 2022). Many *in vitro* studies have demonstrated that insect protein has hypoallergenic,

anti-inflammatory, or even therapeutic properties (Zielińska et al. 2017, Nowakowski et al. 2022). These findings suggest that insect protein is characterized by low allergenic potential. Based on these observations, pet food manufacturers rely on insects in the production of hypoallergenic food and specialty diets for dogs with FRE. However, the safety of insect-based food for non-livestock animals has not been sufficiently studied (Jin et al. 2016, Selaledi et al. 2020, Gałęcki et al. 2023). Therefore, feeding trials should not be conducted directly on dogs due to the possible adverse effects of the tested products. Unless properly studied, the claim that insects deliver benefits for dogs may mislead pet owners and exert adverse health effects in the long term. These risks could be exacerbated by the lack of certification requirements for hypoallergenic pet food.

Insects are highly suitable for dog nutrition on account of their high digestibility, high protein and fat content, low pH of the canine stomach, the length and function of the canine gastrointestinal tract which has evolved to digest meat, the absence of a direct connection between the cecum and the ileum in canine species, and high protein requirements of dogs (Simpson 1993, Smeets-Peeters et al. 1998, Bosch et al. 2014, Bosch et al. 2016, Hong et al. 2020). However, insect-based diets could also have certain disadvantages. Above all, despite the fact that dogs genome contains chitinase protein-coding genes (Bussink et al. 2007), the degradation of chitin in intestinal tract is low (Okamoto et al. 2001, Bosch et al. 2016). Carnivore parasites can use insects as intermediate hosts (Voge and Heyneman 1957, Woodroffe et al. 2004, Ferrantelli et al. 2010). Edible insects are also a potential source of antinutritional factors (Rumpold and Schlüter 2013, Weru et al. 2021). Insect-based foods that are currently available on the market have not been scientifically evaluated. The efficacy of insect protein in the treatment of FRE has never been studied. The only insight that can be gleaned from the literature is that dogs may clinically express allergenic cross-reactivity with mealworm proteins (Premrov et al. 2021).

The health implications of insect protein should be analyzed in clinical trials, and the results can be used to formulate safe and effective dog food. Clinical trials should be conducted on laboratory animals (such as rats) fed the tested food under controlled conditions. In the next stage, feeding trials should be performed in a real-world setting with the involvement of dogs that are fed by owners in the home environment. The following factors should be considered to determine the applicability of insect protein as a source of nutrition for companion animals: (1) the animals' overall health (body mass, body condition score, diarrhea, behavior,

blood morphology and biochemistry parameters); (2) gastrointestinal health (macroscopic changes in endoscopic evaluations, histological analyses, microbiome analyses); (3) immune health (cytokine analysis, cytometric analysis of lymphocyte subpopulations). The results of gastrological and histological tests can provide valuable information about the influence of insect protein on the canine digestive tract. The impact of insect-based food on the canine gut microbiome has been poorly investigated to date. Jarrett et al. (2019). found that diets containing cricket supported the same level of gut microbiome diversity as a standard healthy balanced diet. These results support crickets as a potential healthy, novel food ingredient for dogs (Jarrett et al. 2019). Immunity tests should also be carried out to determine the effects of insect protein on gut-associated lymphoid tissue (GALT), local inflammations, and the activity of the canine immune system. These tests could generate important insights because the immune system can play a role in FRE (German et al. 2001, Allenspach et al. 2006, Mowat 2019, Siel et al. 2022).

A large population study involving various breeds of dogs living in the domestic environment will pose the greatest challenge. Pet owners have different habits, and domesticated dogs are fed various diets and are kept under various sanitary conditions (Kamleh et al. 2020, Evason et al. 2022, Prata 2022). The progression and etiology of FRE can also differ across individual animals (Allenspach et al. 2006, Kawano et al. 2016, Nagata et al. 2020, Procoli 2020).

Various measures should be initiated to improve the wellbeing of pets affected by CE and FRE (Procoli 2020, Benvenuti et al. 2021, Glanemann et al. 2021, Tolbert et al. 2022). Innovative pet food can attract the interest of veterinary professionals, in particular gastroenterology specialists. The proposed initiatives will support the introduction of insect-based pet food to veterinary practice. Marketing campaigns targeting pet owners could increase the consumers' interest in edible insects (Siddiqui et al. 2023) and act a milestone in the development of innovative products containing insect protein, such as dietary supplements, prebiotics, and treats. Such measures will increase the demand for insect-based components and stimulate the development of the insect farming industry (Van Huis 2020, Niyonsaba et al. 2021, Valdes et al. 2022).

Future directions

The exploration of insect-based pet food opens up numerous opportunities and challenges in the realm of veterinary medicine, animal nutrition, and the pet

Table 1. Research and development areas in insect-based pet food.

Research focus	Challenges
Clinical trials and certification requirements	<ul style="list-style-type: none"> • Conduct extensive clinical trials on the use of insect-based pet food for companion animals, especially dogs with food-responsive enteropathies (FRE). • Develop rigorous certification requirements for hypoallergenic pet food containing insect protein to ensure safety and efficacy.
Gastrointestinal health and microbiome studies	<ul style="list-style-type: none"> • Investigate the impact of insect-based pet food on the canine gut microbiome, gastrointestinal health, and histological structure of the digestive tract. • Examine macroscopic changes, histological analyses, and microbiome evaluations to understand how insects affect the gastrointestinal system.
Immune system effects	<ul style="list-style-type: none"> • Assess the influence of insect protein on the canine immune system, particularly the gut-associated lymphoid tissue (GALT) and local inflammations. • Examine cytokine analysis and cytometric studies of lymphocyte subpopulations to understand the immune response to insect-based nutrition.
Allergenic potential and cross-reactivity	<ul style="list-style-type: none"> • Investigate the allergenic potential of insect-based pet food, particularly examining cross-reactivity with other allergenic proteins. • Determine if insects can serve as safe and hypoallergenic protein sources for dogs with food allergies.
Large population studies	<ul style="list-style-type: none"> • Conduct large-scale population studies involving various dog breeds living in diverse domestic environments. • Understand the progression and etiology of FRE, considering individual variations, dietary habits, and sanitation conditions.
Consumer acceptance and marketing	<ul style="list-style-type: none"> • Explore strategies to enhance consumer acceptance of insect-based pet food for companion animals. • Develop marketing campaigns targeting pet owners to increase awareness and demand for these innovative products.
Intellectual property protection	<ul style="list-style-type: none"> • Strengthen intellectual property protection for insect-based pet food formulas and related research to prevent counterfeit products in the market.
Transparency and education	<ul style="list-style-type: none"> • Promote transparency in pricing, manufacturing, and product information for insect-based pet food. • Implement educational campaigns to provide consumers with accurate and reliable information about the benefits and safety of these products.
Pet food formulation and quality control	<ul style="list-style-type: none"> • Develop standardized pet food formulations based on insect protein to ensure consistent quality and nutritional value. • Establish rigorous quality control measures, including ingredient sourcing, storage, and supplier assessments.
Diverse insect species and farming practices	<ul style="list-style-type: none"> • Explore the utilization of a wider range of insect species for pet food to increase biodiversity and sustainability. • Investigate innovative and sustainable insect farming practices to meet the growing demand for insect protein.
Legal and administrative compliance	<ul style="list-style-type: none"> • Stay updated on evolving legal and administrative requirements related to insect-based pet food. • Ensure full compliance with regulations and standards, adapting production processes as needed.
Competition and marketing strategies	<ul style="list-style-type: none"> • Prepare for competition in the insect-based pet food market by developing unique marketing strategies and continuously innovating food formulas.
Collaboration with veterinary professionals	<ul style="list-style-type: none"> • Foster collaboration with veterinary practitioners, particularly gastroenterology specialists, to bridge the gap between innovative nutritional solutions and clinical application.

food industry. The following key unanswered questions, challenges, and future directions were placed in Table 1.

Mentioned development directions will be critical for advancing the subdiscipline of insect-based pet food over the next 3-5 years. Through rigorous research, comprehensive testing, and strategic marketing efforts,

insect-based pet food can emerge as a safe, effective, and sustainable option for companion animals, meeting the evolving needs and preferences of pet owners and promoting the growth of the insect farming industry.

Conclusions

In conclusion, the safety of insect-based pet food has not been sufficiently investigated. There is some evidence to indicate that insect protein has low allergenic potential, and that it does not influence the canine immune system which plays an important role in the pathogenesis of FRE. The impact of insect-based foods on the gut microbiome and the histological structure of the digestive tract in companion animals remains unknown. For this reason, pet food formulas containing insects should be thoroughly analyzed to determine their efficacy and safety. The results can be used to substantiate product claims and to ensure that only tested and safe products are placed on the market.

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