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Insects as a complete nutritional source

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EDITORIAL

Abstract

For most animals insects are used as part of a diet, but strict insectivores only consume insects and other invertebrates. For them, all nutrients need to be available in suitable proportions to prevent nutritional deficiencies. Common deficiencies pertain to the vitamins A and D, and the mineral calcium. Moreover, concentrations of taurine, thiamine, vitamin E, omega-3 fatty acids are seemingly lower in most cultured insects than in wild insects. Mitigation strategies to prevent deficiencies are described, and future studies to further tailor insect composition towards nutrient requirements are suggested.

1. Introduction

In the last decade, interest in the use of insects for food and feed has increased. Researchers have worked on a variety of aspects, including rearing, processing, and consumer attitudes. Often, edible insects are primarily considered a high-quality protein source and other nutrients receive less attention All nutrients need to be available in suitable proportions in often one, or just a few, insect species, when composing a complete diet for strict insectivores. Meanwhile, data on nutrient requirements of the insectivore(s) are largely unknown. However, clinical data on the occurrence of nutritional deficiencies help to identify nutrients of concern. The best-known nutrients of concern are the vitamins A and D, and the mineral calcium (Finke and Oonincx, 2023). However, commercial feeder insects might be deficient in other nutrients (vitamin E, thiamine, omega-3 fatty acids and taurine) for some captive insectivores, as suggested by nutrient analysis (Finke, 2002, 2015).

2. Nutrients of primary concern

Low levels of vitamin A (retinal and perhaps 3-OH retinal) synthesized from ingested carotenoids are present in the compound eyes of insects where retinoid synthesis takes place (Von Lintig, 2012). Insect larvae, which lack compound eyes have essentially non-detectable levels of vitamin A as they convert accumulated carotenoids to retinoids during pupation when the compound eyes are formed (Seki *et al.*, 1998; Von Lintig, 2012). Therefore, levels of preformed vitamin A in insects are low. Insects contain highly variable amounts of different carotenoids which they obtain from their diet. Wild insects generally contain higher levels of carotenoids than cultured insects due to differences in dietary intake (Arnold *et al.*, 2010; Eeva *et al.*, 2010; Finke, 2002, 2013, 2015; Newbrey *et al.*, 2013; Oonincx and Dierenfeld, 2012; Oonincx and Van der Poel, 2011). Certain carotenoids can serve as vitamin A precursors and several insectivores are known to be able to convert β-carotene to vitamin A (Cojean *et al.*, 2018; Freel *et al.*, 2022; Ploog *et al.*, 2015).

Vitamin D levels of cultured insects are normally very low. The reason for this is that they are cultured indoors without access to full spectrum light. Sunlight includes UVb radiation, which can convert 7-dehydrocholesterol to vitamin D_3. Both house crickets (*Acheta domesticus*) and migratory locusts (*Locusta migratoria*) synthesize this vitamin if they are exposed to UVb and yellow mealworms (*Tenebrio molitor*) form high concentrations when irradiated with UVb. In contrast larvae of the black soldier fly (*Hermetia illucens*) seem to lack this capacity (Oonincx *et al.*, 2018).

Whereas all insects contain calcium, they generally contain low levels (>0.3% dry matter) because they lack a mineralized skeleton (Barker *et al.*, 1998; Finke, 2002; Finke, 2013; Oonincx and Dierenfeld, 2012; Studier and Sevick, 1992). Some exceptions include wild stonefly nymphs, larvae of the face fly (*Musca autumnalis*) and the well-known black soldier fly (Dashefsky *et al.*, 1976; Studier and Sevick, 1992; Spranghers *et al.*, 2017). These species incorporate calcium and other minerals in their exoskeleton. Data on calcium content of both black soldier fly larvae and prepupae indicate large variations (~50×) in calcium levels (Do *et al.*, 2021; Romano *et al.*, 2023; Spranghers *et al.*, 2017; Tschirner and Simon 2015). This variation is due to dietary concentrations of calcium, and due to other minerals competing for the same absorption and transportation pathways.

3. Other nutrients of potential concern

Vitamin E and omega-3 fatty acid levels in insects are typically a function of these nutrients in insect diets. Cultured insects generally contain low levels of vitamin E and omega-3 fatty acids relative to those found in wild insects (Finke and Oonincx, 2023; Finke, unpublished data). In contrast thiamine appears to be low in several species of cultured insects including crickets and superworms (*Zophobas morio*) (Finke, 2002). Taurine is primarily found in the flight muscles of insects so larvae typically contain little, if any, taurine while their adults and hemimetabolous insects, like crickets, can contain significant amounts (Bodnaryk, 1981; Finke, 2002; Massie *et al.*, 1989; Whitton *et al.*, 1987).

4. Mitigation measures

As nutrient concentrations in insects are primarily a function of dietary levels, increasing these can be done via their diets. Two approaches can be distinguished: short term and long term. With short term diets, a special diet is fed to insects one or a few days, before they are offered to the consuming animal. When this diet, containing high levels of the desired nutrient(s), is consumed by the insect, it is present in the gut. Thereby, it increases the insectivore's nutrient intake when the insect is consumed. This method is called gutloading. Several studies have used gutloading to increase calcium levels of feeder insects, such as house crickets, yellow mealworms, superworms, waxworms (*Galleria melonella*) and silkworm larvae (*Bombyx mori*) (Allen and Oftedal, 1989; Anderson, 2000; Dikeman *et al.*, 2007; Finke, 2003; La'Toya *et al.*, 2017; Strzeleqicz *et al.*, 1985). Gutload diets can also effectively increase the vitamin A content of crickets, yellow mealworms, and black soldier fly larvae (Finke, 2003, Boykin and Mitchell, 2021).

With long term diets, it is not due to the food remaining in the insect's gastrointestinal tract but rather due to these nutrients being incorporated into the tissues of the insect. Studies have shown that by modifying the diet of a cultured insect, levels of carotenoids (mostly β-carotene), vitamin E and omega-3 fatty acids can all be increased to levels similar to those found in wild insects (Borel *et al.*, 2021; Dreassi *et al.*, 2017; Ewald *et al.*, 2020; Finke, 2015; Oonincx *et al.*, 2020a). Contrary to most species, the calcium content of black soldier fly larvae can be modified by long term diets.

A third alternative is the use of supplements that can be used to coat the outside of the insect. This so-called 'dusting' can quickly increase the concentration of certain nutrients, for instance calcium. Two important downsides to this approach are that degradable nutrients, such as fat-soluble vitamins and unsaturated fatty acids, need to be protected from degradation. Moreover, dosing is difficult as it requires assessing the amount adhering to the insect exoskeleton upon the moment of consumption (Li *et al.*, 2009; Oonincx *et al.*, 2020b).

5. Future studies

Current insect production systems are primarily focussed on producing volume at the lowest cost and feed is an important factor in production costs. The chemical composition of their products, which can be considered a part of product quality, is often not considered beyond certain nutrients (mostly protein and fat). However, this can result in insects which are deficient in several key nutrients, which can be problematic if one or a few insect species form the sole diet. In order to produce insects that can be used as a complete nutritional source, future studies should identify ways to increase concentrations via species-specific dose-response studies. The collected data should then be utilised to tailor the concentrations of the nutrients of concern to best fit the expected nutrient requirements of insectivores.

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