Honey bee drone brood used as food

Laura Schiel, Christine Wind, Magdalena Ulmer, Peggy G. Braun, Martin Koethe

Abstract

Interest in insects as novel foods is also growing in Europe. Although around a quarter of the world's population consumes insects as part of their traditional diet, mealworms were the first insects to be approved as a foodstuff in the European Union in 2021. The male larvae of the honey bee, drone brood, are also edible insects with great potential. To date, beekeepers have mostly disposed of drone brood as part of measures to control the bee parasite *Varroa destructor* (varroa mite). However, due to its nutritional composition and appealing sensory characteristics, drone brood can be used as food in a variety of ways. This review article summarizes information on past and potential future uses of drone brood as food and the associated risks.

Keywords: honey bee drone brood, edible insects, novel foods, entomophagy

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Introduction

Insects are an important part of the human diet in many countries around the world, especially in Africa, Asia and Latin America. Approximately two billion people eat insects as part of their diet globally [1]. Using insects as food could help to secure the food supply of the growing global population, as this approach offers certain advantages over current agricultural practices in industrialized countries. These advantages vary depending on the insect species being considered, but they generally include reduced space requirements for rearing the animals, lower water requirements, less greenhouse gas and ammonia emissions, and improved feed conversion rates [1]. Over the past few years, there have been increasing efforts to breed and process insects as food in Europe and to establish legislation for this purpose there. Although there are more than 2,000 edible insect species [e1], only a few species are currently being focused on for commercial use as food. These include mealworms *(Tenebrio molitor)*, buffalo worms *(Alphitobius diaperinus)*, house crickets *(Acheta domesticus)*, tropical house crickets *(Gryllodes sigillatus)*, European migratory locusts *(Locusta migratoria)* and black soldier fly larvae *(Hermetia illucens)* [2].

It is known that the honey bee *(Apis mellifera)* plays a key role in the pollination of many plants. Bradbear (2009) described the honey bee's influence on forestry and agriculture, as well as its role in the production of honey and other products such as beeswax, pollen, propolis or royal jelly in detail [3]. However, bees themselves (various species; in adult and larval stages) are also considered edible and are among the important edible insects in countries such as Thailand, Mexico, Ecuador, and Australia [4, e2–e5].

Any potential use of bee brood as food must be consistent with the crucial role of bees as flower pollinators. Therefore, worker bee brood should not be used as food but only the male drones should (◆ Figures 1–4). Hives produce a surplus of drone brood, so there is no shortage of drones, even if drone frames are placed in the hive and the drone brood is subsequently cut out. This also means that this practice carries no risk of too few queen bees being mated, or of a decline in the bee population. Furthermore, the drone brood's higher susceptibility to the varroa mite, which threatens bee colonies, can be exploited this way [e6]. *Varroa destructor* infests bee colonies, feeds on the fat body of larvae and can transmit viruses, such as deformed wing virus, which can ultimately lead to the loss of the entire colony [e7–e10]. If left untreated, most bee populations infested with the varroa mite die within a few years [5, e11]. Alongside organic acids such as oxalic acid, formic acid or lactic acid, applied after the honey harvest, removing drone brood is an effective way of drastically reducing the mite load in the colony and is a method that can be used even during honey production [6–9]. Usually, once removed, the comb containing the drone brood is melted down to recover the wax, and the drone brood itself is not used further [8, 9].

In Germany, there are approximately 160,000 beekeepers who manage a total of around 1.1 million bee colonies [10]. Assuming two drone combs per colony and about 200 g of drone brood per drone comb cut, and given the recommendation to cut out drone brood three to four times per season, Germany produces approximately 1,320–1,760 metric tons of drone brood annually [8, 9]. This is a small amount compared to the amount of meat slaughtered (9.3 million metric tons in 2021) or the amount of grain harvested (42.4 million metric tons in 2021) in Germany, but it is still sufficient to contribute to securing the protein supply for the growing world population [e12, e13].

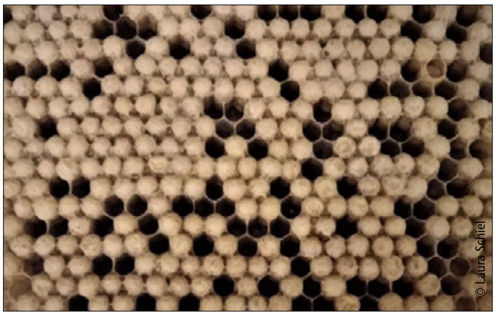

Fig. 1: **Filled drone brood cells.** Compared to the worker bee brood whose combs are closed by a very slightly raised cap, the cap of the drone brood is more noticeably curved and the combs are larger overall.

Fig. 2: **Longitudinal section of a drone comb with drone brood in the stretched larval stage**

Fig. 3: **Developmental stages of honey bee drone brood.** From the round larva (left) to the stretched larva, the prepupa, and finally the pupa (right)

Fig. 4: **Drone brood larvae after separation from the drone combs**

Nutrient composition

Honey bees are holometabolous insects that undergo a complete metamorphosis from larval to pupal stage to adult (imago) in the course of their development. The developmental stage of drone brood is key to its nutrient content because larvae and pupae have different nutrient compositions. Drone brood nutritional values were therefore grouped by stage (larvae, pupae, or "bee brood" if unknown or mixed) based on available data and presented in ◆ Table 1.

The main component is water which accounts for 74.4% of larvae, 79.9% of pupae and 79.7% of bee brood [11–14].

The dry matter content (DM) that can be calculated from this contains about 40% protein in both larvae and pupae (larvae 35.5% of DM, pupae 36.9% of DM, bee brood 41.0% of DM), which is comparable to that of beef and soybeans and is even higher than that of pork [4, 11–17]. Honey bee drones also contain all nine essential amino acids, which means they provide protein of good nutritional quality [11, 13, 16].

The fat content of drones increases during their development from an average of 17.4% of DM for larvae to an average of 18.4% of DM for pupae and can be up to 23.3% of DM on average for bee brood [4, 11–17]. This is lower than the average fat content of beef (56.3%) and pork (69.9%) [11]. Depending on the stage of development and external influences, the fatty acid composition of bee brood is mainly composed of saturated and monounsaturated fatty acids and only a few polyunsaturated fatty acids such as linoleic acid. Palmitic acid, stearic acid and oleic acid are the dominant fatty acids in both larvae and pupae [11, 13].

In the literature, carbohydrate content varies widely across the categories from an average of 27.2% of DM for bee brood, to 37.4% of DM for pupae, and up to 41.1% of DM for larvae. The variations could be due to the fact that the remnants of the pulp-like substance fed to the drone brood (which has a high sugar content derived from the nectar collected by the worker bees) were present in different amounts and that the content was mostly determined only by calculation (100 minus protein, fat and ash content) [11, 13, 15–17].

Ash content is the residue produced by complete combustion (ashing) of the organic components of drone brood and it correlates with the mineral content of drone brood [e14]. The analyzed values ranged from 3.4% of DM for larvae to 6.9% of DM for bee brood [4, 11, 13–17]. Drone brood is a better source of the minerals calcium, magnesium, potassium, iron, zinc, and copper than conventional meats [11, 13]. For example, Ghosh et al. (2016) determined a calcium content of 84.9 mg/100 g for larvae, compared to 18.7 mg/100 g for beef and 37.9 mg/100 g for pork. In contrast, the sodium content is lower in larvae (59.4 mg/100 g) and pupae (60.8 mg/100 g) compared to beef (138 mg/100 g) and pork (83.7 mg/100 g) [11].

The energy content increases slightly as the drones develop, along with the fat content. The average energy content for larvae is 465.4 kcal/100 g, for pupae it is 470.5 kcal/100 g and for bee brood it is 485.3 kcal/100 g [11, 13, 14, 16, 17].

Since drone combs are removed to reduce infestation of colonies with varroa mites as described above, it may also be necessary to consider the influence of infestation on drone brood composition. However, a study by Jonas-Levi et al. (2015) showed that larvae infested with varroa mites did not have a significant change in nutritional composition [12].

Sensory characteristics

Only a few studies have evaluated the sensory characteristics of drone brood in detail [15, 19]. Evans et al. investigated the taste, odor, and texture of drone brood from four locations in Denmark and Norway using a partially experienced panel. The sensory napping quick method was used and the panel were asked about additional descriptors. Different results were found for different stages of development: While pupae were generally described as savory/umami and chewy, larvae were predominantly described as sweet, fruity and softer [19]. Additional descriptors included milky and floral for pupae and creamy, mild and nutty for larvae. Differences were also found for different bee colony locations in some cases. However, some locations were also found to have greater similarity between larvae and pupae than others [19]. The authors then discussed the possible physiological, genetic and feed-related causes of these sensory characteristics. They estimated that among these three parameters, the influence of genetics and physiology was rather low, although the focus

	Larvae			Pupae			"Bee brood"		
	Mean	Range (Min–max)	References	Mean	Range (Min–max)	References	Mean	Range (Min–max)	References
Water [%]	74.4		[22]	79.9	(79.3–80.5)	[22, 23]	79.8	(76.8–82.8)	[26, 27]
Dry matter [%]	25.6		[22]	20.1	(19.5–20.7)	[22, 23]	20.3	(17.3–23.2)	[26, 27]
Protein* [% DM]	35.5	(31.6–37.6)	[7, 22, 24, 25]	36.9	(26.6–44.8)	[7, 22–25]	41.0	(34.0–45.7)	[25–28]
Fat [% DM]	17.4	(14.5–19.0)	[7, 22, 24, 25]	18.4	(16.0–20.2)	[7, 22–25]	23.3	(20.3–31.2)	[25–28]
Carbohydrate [% DM]	41.1	(36.0–46.1)	[22, 24, 25]	37.4	(27.0–50.8)	[22, 24, 25]	27.2	(22.1–34.5)	[25, 26, 28]
Ash [% DM]	3.7	(3.4–4.1)	[7, 22, 24]	3.6	(3.5–3.8)	[22, 24, 25]	4.6	(3.5–6.9)	[26–28]
Energie [kcal/100 g DM]	465.4	(455.8–475.0)	[22, 25]	470.5	(465.0–476.0)	[22, 25]	485.3	(475.0–498.6)	[25–27]

* The protein content was taken from the original reference or recalculated to match the current nitrogen to protein conversion factors of 5.6 for larvae and 4.9 for pupae, respectively [18]. For "bee brood", a mean factor of 5.25 was used for recalculation, assuming a mixture of 50% larvae and 50% pupae.
DM = dry matter

Table 1: **Nutritional values of honey bee drone brood.** The values were grouped by stage (larvae, pupae, or "bee brood" if unknown or mixed) based on available data.

of the study allows only very limited conclusions to be drawn about these three parameters [19]. In another study, larvae and pupae were analyzed for the presence of volatile constituents using gas chromatography-mass spectrometry (GC-MS) and the results were correlated with the results of a sensory panel [15]. Most of the compounds detected in the samples were odorless, but some of them were compounds responsible for specific odor characteristics. There were overlaps, but also differences between the various developmental stages. Substances such as 2-methylbutanal, 3-methylbutanal and 2-pentanol, which cause a malty odor, were detected only in pupae, as was 2-heptanone, which causes a cheesy to fruity odor, and dimethyl sulfide, which causes a sulfurous to oniony odor. Buttery-smelling diacetyl and woody 3,7-dimethyl-1-octene were detected only in larvae; 3,7-dimethyl-1,3,6-octatriene, which is described as tropical and green, was found in greater amounts in larvae than in pupae [15]. However, the trained sensory panel did not perceive these exact characteristics in their analysis. Overall, panelists described larvae and pupae using attributes such as milky, buttery, nutty, mealy, musty, and mushroom-like, and only the larvae were additionally described as caramel-like and sweet. The expected malty smell of pupae was not described. The authors attributed these differences to possible overlapping effects, in which the mixing of volatile compounds can lead to the formation of new odor characteristics. They also emphasize that gaining a better understanding of drone brood flavor profiles may be helpful for future product development [15].

Possible uses for bee brood to date

Although there are already studies on the use of other edible insects, for example on marinating and fermenting mealworms [e15], no such scientific studies are known with regard to bee brood. Nevertheless, opportunities and ideas do exist. For example, there is a recipe book that features dishes with larvae and describes how to make special products [e16]. According to this book, drone brood can be processed in a similar way to chicken eggs. The book contains recipes for soups, main dishes such as a kebab-like product made from a mass of bee larvae on a skewer, snacks, desserts, and a long drink [e16]. In addition, it is reported that dishes made from or containing bee larvae have already been served in gastronomic establishments, such as deep-fried larvae served as "*Bienengrammeln*" ("bee crackling"). Experiments have also been conducted on the production of chocolate mousse or bee ice cream [e17, e18]. In addition, for a limited time, it was possible to buy bee caviar and crispy drones from an Austrian beekeeper [e17, e19]. The bee caviar was cooked, salted drone larvae pickled in sunflower oil, and the crispy drones were salted or unsalted dried drone larvae. The “bee crackling”, bee caviar and crispy drones are now no longer available. Currently, no information about chocolate mousse and bee ice cream is available, so it must be assumed that these products have likely not been developed further.

Drone brood has also been processed using extrusion (◆ Figure 5), an established technology that combines steps such as mixing, kneading, heating, and molding. Many foods are already produced in this way: breakfast cereals for example. This process preserves the nutrients as far as possible and increases digestibility. In the tests, drone pupae were mixed with soy protein concentrate and it was found that they could serve as a meat substitute, for example in hamburgers [20].

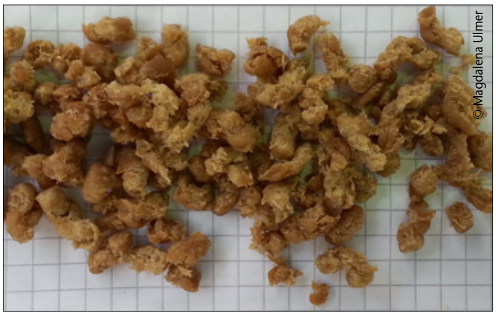

Fig. 5: **Burger ingredient with 30% drone brood and 70% soy protein concentrate**

Another important product is Apilarnil, a food supplement obtained from drone brood combs. It consists mainly of the drone brood larvae themselves and trace amounts of royal jelly, bee bread, honey, propolis and beeswax [21]. It is said to have various biological properties such as antimicrobial and immune system-enhancing effects, as well as androgenic or testosterone-like effects [e20]. In addition, Hamamci et al. (2020) conducted a study to investigate the possible neuroprotective effect of Apilarnil in sepsis-induced brain injury [e21]. Considering the available results on Apilarnil’s mechanisms of action, future studies should demonstrate the extent to which these are reproducible and whether any, and if so, which of these effects are to be expected following intake of drone brood.

The legal context

Drone brood for human consumption falls under the definition of “food” in Regulation (EC) No. 178/2002 [22]. It is classified as a novel food under Regulation (EU) 2015/2283 and may only be placed on the market after a safety evaluation and approval by the European Food Safety Authority (EFSA) [23]. According to the transitional arrangements established under this Regulation, an insect species may continue to be placed on the market until a decision is made on the corresponding application for approval, provided that this application was submitted to the European Commission (EC) by January 1, 2019, and

provided that this species was lawfully on the market in the European Union (EU) prior to the entry into force of the Regulation (by January 1, 2018) [23, e22].
These conditions were met for drone brood, but the decision on whether to apply the transitional arrangements is up to each member state, and in the case of Germany, it is up to each federal state due to Germany's federal system [24, e22-e24]. If drone brood is used for a certain purpose, it may continue to be marketed for that purpose in accordance with the specifications and conditions of use stated in the application until a decision is reached [24, 25]. The food business operator is responsible for the safety of the products placed on the market in this context in accordance with Regulation (EC) No. 178/2002 [22].
In Germany, the requirements of the Food Hygiene Regulation (*Lebensmittelhygiene-Verordnung* – LMHV) must also be complied with when placing products on the market. If the ectoparasite *Varroa destructor* remains on drone brood intended for human consumption, this could be considered to have an adverse effect on the product under the Food Hygiene Regulation if it is considered an animal pest [26]. A study by Azizi et al. in 2008 demonstrated that it is possible to separate mites from adult honey bees [e25].
In addition, until further specific regulations are issued, the generally applicable legal provisions apply to production and processing and to products on the market. For example, for labeling requirements, Regulation (EU) No. 1169/2011; for hygiene regulations, Regulation (EC) No. 852/2004 and Regulation (EC) No. 853/2004; and for the assessment of microbiological criteria, Regulation (EC) No. 2073/2005 [e26-e29].

Hazards and risks

Microbiological risks

Possible sources of contamination with microbiological contaminants include the gastrointestinal tract of the drone brood and the nectar or pollen with which they are fed, but also, for example, the beekeepers, their equipment and components of the hives [27]. The natural gastrointestinal microbial flora of honey bees includes yeasts, Gram-positive bacteria (such as *Bacillus*, *Bacteridium*, *Streptococcus*, *Clostridium* spp.) and Gram-negative bacteria (such as *Achromobacter*, *Citrobacter*, *Enterobacter*, *Erwinia*, *Escherichia coli*, *Flavobacterium*, *Klebsiella*, *Proteus and Pseudomonas*) [27]. Drone brood is enclosed in combs along with a pulp-like substance that feeds them. Therefore, it is not possible to empty the gastrointestinal tract prior to slaughter by depriving them of food, as is practiced in other commercially bred species [e30]. This means that the microorganisms contained in the gastrointestinal tract can also be found in the food product.
However, external inputs of microorganisms are also relevant. The Implementing Regulations (EU) 2021/882, (EU) 2021/1975, (EU) 2022/169 and (EU) 2022/188, which were adopted in the context of the approval of mealworms, European migratory locusts and house crickets, also established microbiological and other criteria. They include requirements for total aerobic plate count, yeasts and molds, *Escherichia coli*, *Salmonella* spp., *Listeria monocytogenes*, sulfite-reducing anaerobes, presumptive *Bacillus cereus*, presumptive *Enterobacteriaceae*, and coagulase-positive Staphylococci [28–31]. In a study by Herren et al. (2021), *Bacillus cereus*, coagulase-positive Staphylococci, *Enterobacteriaceae*, and *Escherichia coli* were detected, but each of these was below the detection limit of reference methods, and no Salmonella was detected. Qualitative and quantitative detections of *Listeria monocytogenes* below the detection limit of 10 colony forming units (CFU)/g were also found [32]. While these levels do not pose a direct risk to consumers, the results do highlight the need for compliance with strict hygiene regulations and for the application of the measures required by Regulation (EU) 2073/2005 [e29].

Allergenicity

It is possible for food and inhalant allergies to be triggered following intake of edible insects as a result of primary sensitization. In addition, cross-reactions are possible in individuals who are allergic to crustaceans and house dust mites [2, 33, 34]. Furthermore, allergens ingested by the insects via the substrate could also play a role [2, 33]. In the case of drone brood, these would primarily consist of honey components such as glandular secretions, propolis components of the wax, and nectar and pollen. It is also possible to be allergic to honey, but this is relatively rare. The symptoms can range from mild symptoms such as itchy oral mucosa to systemic symptoms and anaphylactic shock [e31–e34].
As there are no official requirements for allergen labeling of insects, honey or their components as yet, adding this information to the labels of drone brood products is recommended until relevant studies are available. The requirements of Implementing Regulations (EU) 2021/882, (EU) 2021/1975, (EU) 2022/169, and (EU) 2022/188 provide guidance for insect-specific allergen labeling with regard to potential cross-reactions [28–31].

Pesticides

Drone brood is fed with honey and pollen, for example. This means that pesticides could enter the drones and accumulate within them [35, e35–e38]. At present (March 2022), no data are available regarding pesticides in honey bee drone brood. Studies by Houbraken et al. (2016) have shown that pesticides ingested via the substrate can accumulate in insects [35]. Shin et al. (2020) also detected the urea pesticides flufenoxuron, lufenuron, and noruron (Norea) in mealworms grown commercially for consumption at levels of up to 220.7 μg/

kg (lufenuron) [36]. In our own investigations (2019 and 2020), 37 drone brood samples, taken as far as possible from the vicinity of fruit trees, were collected from beekeepers in the areas of Lake Constance, Freiburg, the Black Forest and the Leipzig area. The samples were tested for the possible presence of 292 parameters by liquid chromatography-mass spectrometry. No pesticide residues were detected in any of the available samples (Schiel et al., unpublished data). Since there are no specifications for maximum pesticide content in accordance with Regulation (EC) No. 396/2005 for drone brood specifically, the detected pesticide levels in honey bee drone brood must not exceed a value of 0.01 mg/kg according to the specifications of this regulation [37].

Other hazards and risks

In the case of drones, the issue of toxic substances produced by the insect itself is not relevant because, unlike worker bees and the queen, drones do not have a stinging apparatus and therefore do not have a venom bladder. This means that no such substances are produced in the larval and pupal stages [38, e39]. Consequently, care must always be taken during separation to ensure that worker brood does not become mixed in with drone brood. No other possible toxins produced by drones themselves have been identified.

There could be other risks associated with medications used to treat bee colonies. Currently, the only veterinary medicinal products approved for use in honey bees in Germany are those for the treatment of varroosis [39]. However, with one exception, these medications are only permitted to be used after the honey harvest in late summer or autumn, whereas the removal of drone brood frames for varroosis control takes place in the months of April to July [9]. The single exception is the medication VarroMed®, which can also be used in spring. However, it is recommended that this medication not be used during the honey harvest, or when the supers are set up [e40]. Accumulation of the medication in honey could result in non-compliance with the free acid content requirements of the German Honey Regulation *(Honigverordnung)* and render products unfit for sale [40].

To exclude any risk to consumers, the use of drone brood as food should adhere to the same waiting periods as apply to the use of medications in honey production, and checks should be carried out to detect any residues of these medications.

Discussion and conclusions

Drone brood has a valuable nutrient composition and although there are few studies to date that look more closely at the sensory characteristics of bee larvae and pupae, many positive reports are available.

The existing products and product ideas also show that drone brood has great potential as a food raw material or ingredient. The disappearance of products that were previously available could be due to the fact that drone brood has not yet been approved as a food in the EU. With the entry into force of the Implementing Regulations (EU) 2021/882, (EU) 2021/1975, (EU) 2022/169, and (EU) 2022/188, criteria for insect species (mealworms, migratory locusts, and house crickets) were published for the first time, and these can also be used to guide the assessment of drone brood until species-specific guidelines are adopted [28–31]. Because honey bees are not bred under strictly controlled conditions as other edible insect species are, but are instead bred in an open system, further studies should be conducted for consumer protection, and corresponding legal requirements should be published. In addition, regular microbiological tests and checks for hazardous substances should be carried out, and prior to consumption, the insects should be subjected to treatment procedures that can minimize the hazards and risks. The recommendations for mealworms, e.g. heating at 90°C for 5 to 7 min, could be followed here [e41].

Using honey bee drone brood as food would also make sense from an ecological point of view and could make an important contribution to securing food supplies for a growing human population. This would also provide beekeepers with an additional source of income if they were to produce their own products from the larvae and market them locally or sell the drone brood as raw material to regional companies that could process them further. If such processing companies were to collect drone brood from several beekeepers in the vicinity and process and market it from a single source, they would be able to achieve the efficiency of larger companies and optimize the possibilities of utilization.

Conflict of Interest
The authors declare no conflict of interest.

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