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State of the Art Report: Insects as Food and Feed

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INTRODUCTION

FAO has considered insects as food since 2003 [1] and is promoting consumption of insects (entomophagy) in the Western world because of the possibilities for sustainable production it offers. Insects as food are considered to leave smaller ecological footprints than conventional livestock (beef, pigs, and poultry) regarding feed, land and water needs, as well as greenhouse gas and ammonia emissions [2-7]. As an example regarding water, taken from a recent TV documentary, if a family of four people got their protein need from insects one day a week instead of from conventional livestock, over a year they would save the planet about a million Liters of water [8]. This is in agreement with figures above.

One of the main reasons that insects for food in general have such positive environmental properties is that they are cold-blooded and thus use no energy to maintain their body temperature, in contrast to mammals (beef, pig) and birds (poultry), so their feed conversion is considerably more effective than that of conventional livestock [1]. However, differences in feed conversion may also have other reasons, and are complicated to explain, as discussed in a recent review of Life Cycle Assessments of edible insects [9]. In addition, insects can be reared on organic side streams [1,10]. For example, mealworms can recycle organic residues into high-quality potential feed rich in energy, protein and fat [11].

Insects as food are generally considered as healthy, nutritious alternatives to conventional meats such as chicken, pork, and beef. They are rich in protein, 40-60% of dry matter, with content of essential amino acids similar to beef and soy. Unsaturated fat content is 10-30% of dry matter, and they are high in calcium, iron and zinc [1,5,12,13]. However, there are significant differences depending on insect species, rearing method and feed, etc. [14,15].

Referring to nutritional and environmental data for edible insects, one might think that “The supreme irony is that all over the world monies worth billions of rupees are spent every year to save crops that contain no more than 14% of plant protein by killing another food source (insects) that may contain up to 75% of high quality animal protein” [16].

Approximately, 2000 insect species are consumed as food in some part of the world [1]. Many of these are caught in the wild in tropical areas. Regarding rearing of insects for food or feed in non-tropical areas, a few species (or groups of species) dominate. These are crickets, black soldier fly and other fly larvae, and mealworms, although other species are also popular (e.g. grasshoppers). This paper focuses on the production of mealworms for food.

Mealworms are considered easy to breed and feed, and basic instructions are readily available [11]. For an overview scheme [3]. There is also a large amount of advice available on Internet (e.g. Sialis, Instructables, and WikiHow).

Mealworms are omnivorous and can eat all kinds of a wide range of plant materials as well as animal products. They are typically fed on cereal bran or flour supplemented with protein sources. Mealworms are able to utilize small amounts of water contained in dry feeds, but it is preferable to provide them with a source of water for better productivity. They may have up to 6 generations per year [11]. There are also many ideas on how to improve mealworm feed at low cost, such as by including brewer's spent grain [17] or fiber [18].

To briefly mention other insects as food, regarding fly larvae as food, it has been suggested to use the Mediterranean fruit fly larvae (*Ceratitis capitata*) [19,20]. Compared to other edible insects, they are claimed to have the lowest ecologic footprint.

Crickets are very popular in the USA [21].

This State-of-the-Art report has originated in a Swedish national project on insects as food and feed, supported by Vinnova. The aim of this project is the aim of this project is to promote the use of insects as food and feed, since they have a number of advantages, as outlined above. The project aims to address significant barriers for insects as food and feed.

- Legislation;

- Public acceptance, culinary aspects such as recipes, taste;

- Supply/production;

- Logistics;

- Health, safety, environment, social aspects;

- Business models, economy.

This State-of-the-Art report provides background for the points above.

SCALING-UP OF MEALWORM PRODUCTION

Instructions for hobby breeders are common on Internet, even for a large hobby scale, see e.g. [22,23]. Regarding automation of production, information is not easy to obtain, for obvious commercial reasons. However, it is clear that many companies and development research groups are studying or even implementing this. Examples are the Danish, et al. [24], funded by Eurostars, the French company [25] and the Dutch company [26]. There are also consultants for automation, such as Nordic Insect Economy in Finland 2016, as well as patents (USA Patent, 2011). An outline of steps to be automated can be found in Rumpold and Schlüter et al. [27].

In Sweden, the largest producer of mealworms (and other insects) is Cricket Express (2016), for zoos etc. Within Sweden, there is as yet no other commercial company that rears mealworms. Nutrient (2016) is the first Swedish entopreneur breeding its own mealworm, producing oil and a dry powder. Tebrito et al. [28] can also produce enriched protein powder and oil on a pilot scale.

The influence of the choice of feed or other parameters on properties such as taste is of great interest [29,30]. The idea is to infuse live mealworms with different spices, so they will have much more inherent flavour when cooked. Also worth studying is if the choice of feed can affect the protein content in the specific insect species.

INSECTS POSSIBLE TO FEED ON FORESTRY PRODUCTS

Worldwide, millions of tonnes of organic wastes are generated annually in the forest industry during the relevant industrial processes, but most of these wastes are discarded [31]. Only a minor proportion is used, mainly for biofuel and secondarily for compost production. These organic wastes comprise huge lignocellulose and nutrient stocks [32] and can be valorised for various edible insect species during a wood biodegradation process [33].

Traditionally, most insect species used for food purposes have been harvested in the wild from natural forests. Despite this, there is a significant lack of knowledge about the life cycle, population dynamics and management of many edible forest insects [34].

Knowledge concerning the relationships between edible insect harvesting and general forest management is limited and is mainly restricted to bees and silkworms at present. However, there are many examples worldwide of such symbioses between humans and insects [35].

In Africa, edible caterpillar management is based on young caterpillar larvae brought back from the forest and placed on acacia trees, where they are reared until they are ready to eat, while other insect harvesting involves cutting tree branches or felling trees [35].

In Japan, the large larvae of *Batocera lineolata* (Cerambycidae) collected from living or dried wood are considered safe to eat raw but, when collected from rotten wood, parasite infections have been reported [36]. In Australia, witchetty grub refers to the large, white, wood-eating larvae of several moths (Cossidae and Hepialidae) and long horned beetles (Cerambycidae). However, the term applies mostly to the larvae of the cossid moth [1]. The grub is the most important insect food of the desert [37].

In Asia, Africa and the Western Pacific, Asiatic rhinoceros beetle or coconut rhinoceros beetle, a palm insect pest, is considered edible [38]. It breeds in standing dead coconut palms, stumps and logs on the ground, as well as in other types of decaying wood, etc.[39].

Forest entomologists consider insects a problem and current research within forest entomology is focused almost exclusively on pest management with the use of chemicals or integrated pest management programmes. According to Schabel et al. [36], this perspective could change with entomoforestry, i.e., the management of trees and forests to promote production of edible and other useful insects, and with the establishment of a modern, innovative and sustainable forest-based edible insect industry.

Forest wood-feeding insects are mainly herbivores, but display wide variation in their utilisation of food substrates, ranging from wood to artificial diets [40,41] and through a symbiotic relationship with their gut microflora which enriches their diet, via various biochemical pathways, with essential amino acids, vitamins and sterols [41].

The insect gut acts as a reservoir for a large variety of microbes [42]. Biodegradation and digestion of dead wood lignocellulose and hemicellulose in xylophagous (wood-eating) insects is achieved through passage of the material into the gut, where it is acted upon by the microflora [43,44]. Thus the barrier to lignin degradation in wood-feeding insects can be overcome by: a) Feeding on pre-degraded wood, b) Exosymbiotic relationships with wood-degrading fungi and c) Direct degradation by insect species that feed on the inner wood of living and healthy trees [45].

QUALITY, SAFETY AND LEGISLATION

Presently, insects as food within the EU are covered by EC Regulation 258/1997 (EC Regulation 258/1997). According to this, insects are considered novel foods, since they have not been consumed to any significant extent within the EU before May 15, 1997. This means that insects for food are not allowed to be reared nor marketed unless each specific species has been deemed as safe and approved by the European Commission. EFSA has been asked to publish guidelines for what documentation that is required for an application for approval. These guidelines are still pending.

Sweden complies with the present regulation, as do most other countries. However, some other countries (such as Belgium, the Netherlands, France, UK, Denmark) are not as strict regarding whole insects, since the text is not completely clear, mentioning ”food ingredients isolated from animals” but not entire animals (EC Regulation 258/1997, Article 1e).

As a response to discussions regarding safety as food, the European Food Safety Authority (EFSA) has published a risk profile [46,47]. It is a document covering all aspects of food safety. It does not give any concrete answers, but points to factors that need to be addressed. The overall conclusion is that the risk of using insects as food is no greater than the risks using other animals. Some specific points are that the main risk are the feed substrates, not the insects themselves; that mammalian prions (responsible for BSE) cannot replicate in insects; and that the level of chemical accumulation (for instance of heavy metals) is unclear, and needs to be further studied.

The EC Regulation mentioned above (258/1997) will be replaced by a new regulation, EC 2015/2283, which will apply from January 1, 2018 [48,49]; EC Regulation 2015/2283, Article 36). According to this, there will be special rules for “traditional foods from third countries”, which may simplify the process regarding a number of insect species. EFSA has recently published guidelines for what documentation that is required for an application for approval according to this regulation [50]. This requires an approval, based on a risk assessment of the specific use (at product level), e.g. Insect meal: For use in bread, pasta, snacks; Insect protein: For use in shakes, processed meat products, etc.

Belluco [51] go through available data regarding food safety and nutrition. They conclude that there is a possibility for humans to consume some species with no additional hazards in comparison with usually eaten animal products.

Microbiological aspects of storing mealworms is one of the critical points to address, and has been the subject of a number of studies. For surface microorganisms, Klunder et al. [52] tried heating, drying and lactic fermentation and found these techniques promising; the remaining potential risk was due to spore-forming bacteria. Vandeweyer et al.

[53] found that commercially obtained batches of mealworm for food, obtained from two different companies contained high amounts of microorganisms. Vandeweyer [54] studied the effect of blanching, followed by chilled storage or microwave drying. The number of vegetative cells was reduced to a large extent by blanching plus drying; however, the number of bacterial endospores was reduced only slightly.

EXTRACTION/SEPARATION OF PROTEIN, FAT, AND CHITIN

The FAO has considered insects as food since 2003 and is promoting consumption of insects in the Western world because of the possibilities for sustainable production it offers [1] and because Western food culture and gastronomy influences consumption trends in other parts of the world. Western societies are reluctant to eating whole insects and therefore food ingredients based on insects and included in other products can be alternatives [1]. It is also possible to extract protein, fats, chitin, minerals and vitamins from insects.

Methods for oil and protein extraction from mealworm [55], and honey bees [56], have been reported, and the quality of the extracts is affected by the extraction procedure. Extraction and characterization of gelatin from two edible Sudanese insects has also been performed [57]. The insect gelatin could be used to replace gelatin from pigs and cows, as insects are not associated with Bovine Spongiform Encephalopathy (BSE) and could be an acceptable Halal product. Oil can be extracted by organic solvents or physical expelling, but safety, and environmental and health issues have increased concern regarding industrial processes [58]. Ethanol is a safe organic solvent which has been investigated for defatting soybeans [59], and ground maize [60] defatting for human food purposes [58]. Ethanol extraction has been used to separate fat and protein in mealworms [13]. Ethanol is also suitable as an extraction solvent for defatting food materials to be used intended for further protein extractions. The extracted protein can be characterised using water absorption capacity [59] and fat absorption capacity [61].

According to previous researchers, fresh yellow mealworm larvae contain about 15% fat and 20% protein [62,63]. Our team recently reported work on mealworm protein extraction and characterization of a resulting protein extract [13]. Freeze-dried yellow mealworm larvae contained 33% fat and 43% true protein (dry matter basis). The true protein content of Yellow Mealworm Protein Extract YMPE was about 75%, with an extraction rate of 70% in optimized extraction conditions. The lowest protein solubility was found at pH 4-5 in water and solubility was reduced by salt addition. Rheological tests indicated that temperature, sample concentration, addition of salt and enzyme, incubation time and pH influence YMPE gelation. Thus the functional properties of YMPE could be modified to fit different food applications and thus has a great potential as a food ingredient.

CONSUMERS' ATTITUDES

There are a number of reasons to use insects as feed and food. These reasons refer especially to climate issues but also to nutrition. For example van Huis has demonstrated the relevance of eating insects, known as "entomophagy", drawing attention to health and environmental aspects, but also to livelihood issues. However, we have to bear in mind that the consumer acceptance of this use is crucial for the success of implementing insects as feed and food in daily life.

When studying acceptance of new food it is of importance to consider that humans are generally afraid of new food that originate from animals [64]. In most Western cultures, eating insects is taboo, as many of these are regarded as disgusting by a majority of the population [65,66]. However, many other cultures include insects as a daily part of their diet, where it is not strange at all to eat insects [1]. Payne [67] points out that since most acceptance studies are performed in traditionally non-insects eating cultures, the results from these only show a hypothesized engagement of consumption.

In one study, consumer acceptance of food with insects was investigated with a test food, a vegetable soup with bee larvae. The larvae were included as a visible or non-visible ingredient in the soup. It could be concluded that the different variants of soup were acceptable from a consumer standpoint, but the soup that contained non-visible bee larvae was accepted to a higher extent than soups with visible larvae [68]. The results are consistent with a recent study showing that the use of insects in food could be considered as slightly positive. The results showed that use of "insect-flour" with non-visible insects has a higher acceptance than the use of whole and visible insects as food or food ingredient [69]. In addition, results from a focus group study showed that consumers preferred food products and dishes with milled or non-visible insects over foods with whole or visible insects [70].

In a study with young consumers concerning bars, it was shown that these consumers preferred bars without insects and bars with ground mealworms over bars with whole meal worms. However, the consumers had a similar preference for bars with whole mealworms and ground cricket [71]. This shows that not only the "invisibility" is of importance for the acceptability, but also other factors. For example Korpela et al. [72] showed that familiarity of the food concept may not be enough to prompt consumer's acceptance towards the insect foods.

Liking of a food is often connected to acceptability. Korpela et al. [72] showed for example that a generally more positive attitude towards eating insects does correlate with more positive expected liking. Another recent study showed that an insect-based hamburger was well accepted due to its sensory characteristics; however, information that the hamburger contained insects had a negative impact on the overall liking [73].

To increase acceptability of insects as feed and food, Shelomi [74] suggests insects as feed and as food as an alternative to nuts due to similarities in taste and texture. Recommendations should highlight health aspects such as protein quality and chitin content. Deroy et al. [75] suggests that it would be beneficial if the rationale in insects as food is to show that they are climate smart, healthy and that they are already eaten in many cultures. To convince western societies to accept and eat insects a sensory driven strategy is needed, motivated by psychological motivation and gastronomy.

Today we regard foods such as snails, crabfish, oysters, sushi and frog legs as not only edible but even as delicacies [76-78]. Not long time ago most of these foods were regarded as food for poor people.

In order to find ways of increasing the acceptance of new foods, Payne [67] suggest that research on consumer attitudes and behavior should be more culturally sensitive, systematic and performed in a large-scale context. These should go beyond a focus on consumer psychology, and acknowledge both sociocultural factors and the influence of product attributes on the consumer acceptance. Further, early adopters should be focused upon [79].

APPLICATIONS: FOOD AND GASTRONOMY FOR THE CONSUMER

Insects are a promising and underutilized source of food in the western world. From a nutritional point of view, insects are good sources of proteins, fats (omega-3 and omega-6), vitamins and minerals such as calcium, iron and zinc [12,67,80].

There are studies mentioning culinary aspects of foods based on insects. For instance, in a Danish project bee larvae has been used as a key ingredient in tasty dishes [68,81]. Mealworm is another example of an insect used in food and the flavour is described as mild, nutty and umami-like. It goes well with different types of seasonings. The mealworm can be used to create different types of texture from fine flour to a crispy texture [13]. Mealworm is very useful and can be used in a number of applications. As mentioned above, insects contain unsaturated fat, which can be considered as healthy. The fat content may, however, has a negative impact on the flavour due to its ability to go rancid. Similar problems are well known problems, e.g. in fish and nuts. This implicates careful handling and processing to avoid rancidness [82].

Approximately 2000 different species of insects are estimated to be edible [83] and according to Michael Bom Frost, CEO at Nordic Food Lab (NFL), most of them are delicacies [84]. Concerning nutritional value and sensory aspects, insects as food has a large potential, and the "culinary way" has in focus groups been mentioned as an effective way to reach consumer acceptance for novel foods such as insect-based food products [68,69]. Checking out the web, there are a number of inspiring insect dishes [85].

In a competition held in Sweden 2016 on delicious foods with alternative protein sources, there were three competing participants out of fourteen that used insects as a protein source. One of the competitors was the dish "tenebrio sticks"; developed in an SP project. When comparing different types of textures for this dish, a coarse texture with visible bits of mealworm was preferred [82]. Further, in this competition, the two other mealworm-based food prototypes finished evaluated third and fourth, respectively, in the competition [86].

It should, however, be taken into account that adding insects to a familiar food concept as e.g. 'Chicken nuggets' may turn the concept less familiar and thereby decrease its expected liking [72]. A blind test on Bolognese came to the same conclusion [87].

From a blog on insects as food the following was cited: "If a product isn't an EXACT substitute for another we are accustomed to, it's going to have a very tough time sticking" [88].

INSECTS AS FEED, AND NON-FOOD APPLICATIONS

From a Westerner's standpoint, where insects as food is not yet mainstream, insects as feed may be the natural way of introducing insects in the commercial food chain. Indeed they are natural foods for fish, poultry, and pigs [11]. The recent cost increase of soy meal and fish meal, as well as environmental concerns, is also a driver, and the acceptance barrier may be lower than for insects as food. This is also reflected in the large number of trials on insects as feed all over the world [11].

Generally, the content of nutrients is suitable for livestock feed, and insects can replace 25-100% of soymeal or fishmeal, depending on the animal species. The general ban on animal protein use in livestock feed in 2001 is still in place in the EU, and includes insect protein. A recent European Food Safety Authority (EFSA) opinion paper [46] concluded that any risks associated with insects in human food supply chains are comparable with current mainstream livestock sources, and that a further amendment, allowing insects to be used as feed, is being considered. Notably, insect protein as fish feed has very recently been approved for the EU (All about Feed, 2016), to be effective from July, 2017.

The Black Soldier Fly (BSF; *Hermetia illucens*) is considered by many to be a good candidate for animal feed [89]. It is also remarkable for being able to break down substances that are not degraded in common municipal wastewater plants [90,91].

However, it is obvious that if the fed animals are to be eaten by humans, the feed to the insect needs to be of high enough quality. The Canadian company Enterra has been approved to sell dried BSF larvae as chicken and fish feed [5,92].

Among other uses for insects and insect products, there is one that stands out: the use of chitosan [93], which is expected to reach more than 15 billion USD in 2025. Normally from shrimps, it has a number of applications as a renewable material to replace materials derived from petroleum: waste water treatment, textile and agrochemical industry; food packaging.

OVERVIEW OF THE POTENTIAL MARKET

It is not an easy task to predict the potential market for edible insects, let alone the potential market for mealworm as food in Sweden. Here we present some available predictions.

Regarding industrial-scale production of insects, there are a number of companies producing cricket products in North America. Van Huis [5] lists a total of nineteen. There are also some in Europe, even large ones, such as Ynsect and Proti-farm [5,21].

Getting down to estimates of numbers of market value, Heckmann [94-114] considers it reasonable to assume that in a relatively close future, insect meal may replace 20% of the imported soy meal for Denmark. With that import of 1.5 million ton annually, and selling the insect meal at the price of fish meal (ca 2000 Euro/ton), this would result in annual sales of insect meal of 600 million Euro.

There are a number of business intelligence reports available for most markets, nowadays also for insects as food (and feed). Some overall numbers have been openly published. In Figure 1, we compare available data from some reports (Innovations fonden, 2016; Food manufacture, 2014 [25]. Global Market Insights, 2016; All Latest News, 2016; Persistence market research, 2016), as well as a prediction regarding the project Insect Value Chain in a Circular Bioeconomy (In Valuable; Innovations fonden, 2016).

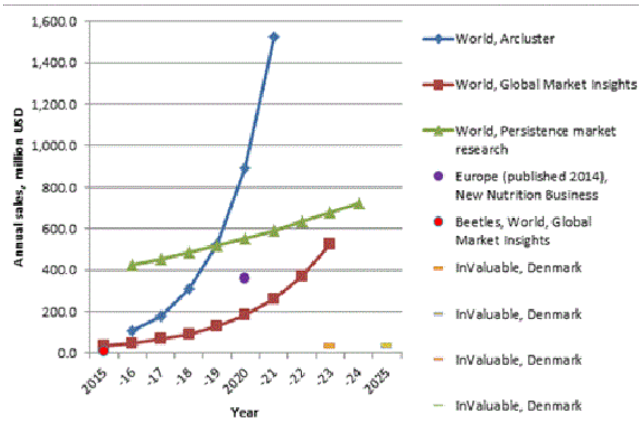

Figure 1: Prediction of sales of insects as food and feed, from open data

As can be seen in Figure 1, there are three predictions (curves) for the general market for edible insects in the world, one point for edible insects in Europe, and one for beetles (mostly mealworm) in Europe. For the world market curves, it is clear that the estimates from the different reports differ very significantly, even in annual growth rates, which range from about 7% to about 70%. These differences may be the result of different views on the barriers, e.g. production cost and capacity, legal issues, and consumer attitudes. However, it is also clear that the entomophagy market can be expected to grow at a considerable pace in the next few years.

The levels of the point data can all be considered to be reasonable, considering which regions (Europe; Denmark) and insects (general; beetles) they refer to. Since even the most informed sources give such spread in prediction, it is not easy to conclude anything regarding the application that is most central to our project, mealworms as food in Sweden. However, it is not unreasonable that we would be close to the numbers for Denmark (reaching 29-43 million USD in 2023-2025).

One business intelligence report not shown in Figure 1 (Lux Research) provides volume data for alternative proteins [103]. Estimating world annual consumption as far as until 2054, they conclude that out of the 943 million tonnes of protein consumed in 2054, 312 million tonnes (33.0%) will be alternative proteins (proteins that are not derived from meat or seafood). Of this, insect proteins will be 37 million tonnes, which is 4.0% of all proteins, and 12.0% of the alternative proteins.

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