Insects raised on food waste

– a new source of feed and food?

Insekter uppfödda på matsvinn – en ny källa till mat och foder?

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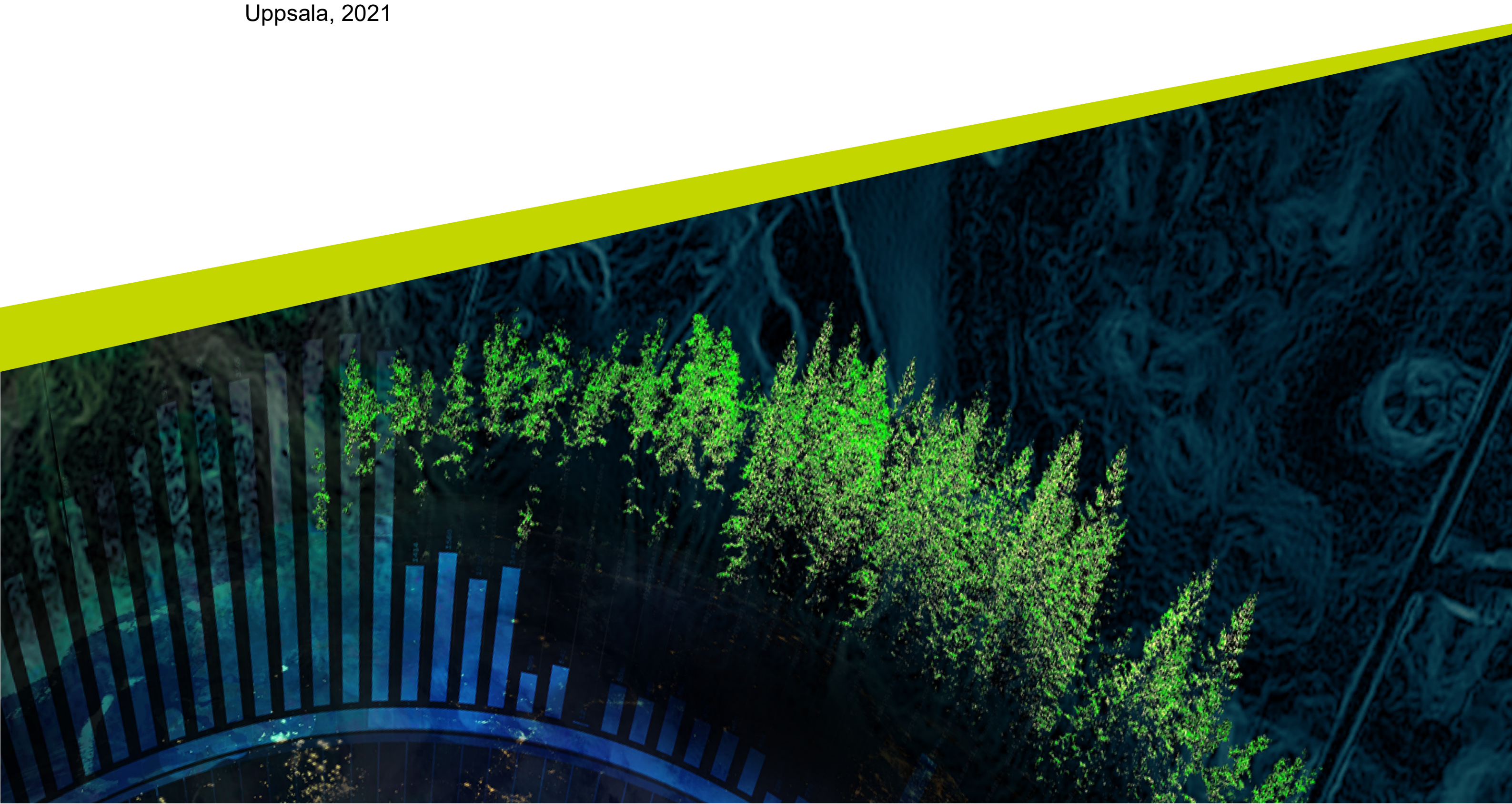

Raising insects on food waste – a new source of feed and food?

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Abstract

An increasing global population demands an increase in food production, while human impact on the planet necessarily must be decreased to decelerate climate change. Resources currently lost as food waste could potentially be utilized to increase world food production amount and efficiency by feeding it to insects. These insects could be used as feed in animal production. The insects could also serve as food for humans, as evidenced by the fact that two billion people regularly consume insects as part of their diet. The aim of this report is to investigate the nutritional and environmental potential of insects as food and feed. This report will also investigate whether varying the feed source affects the nutritional quality and growth of the insects. Since Europeans still, to a large extent, view the concept of eating insects with neophobia and disgust, alternative ways of using insects are relevant. Aquaculture in Sweden is growing rapidly while fish feed is produced in unsustainable ways. Thus, this report also aims to investigate the potential of using insects as feed for fish. Results show that insects in general are safe to eat for both humans and for fish, good sources of protein, fat, dietary fibre and several minerals and vitamins. Many different types of substrate can be used to raise insects although care must be taken to ensure high enough nutritional quality of the substrate to sustain the insects, and not all substrates fit all insect species. Fatty acid composition of insects is impacted by the fatty acid composition in the substrate while amino acid composition does not seem affected. Fish meal in fish feed can be partially or wholly substituted with insects with good results for several insect species, mainly black soldier fly and mealworm larvae. Insects can improve the immunological health and gut microbiota of fish and results indicate that growth may be improved by including insects in the feed. Results on growth and feed efficiency differ widely between different combinations of insect and fish species. In conclusion, insects can be raised on many different substrates to produce a nutritious food or feed. Further research is required on specific food waste types and their effect on growth and safety, to develop realistically usable insect production systems. More research is also required to determine the most productive combinations of insects and fish.

Keywords: insects as food, insects as feed, sustainable food production, fish farming,

Sammanfattning

När världens befolkning ökar behöver livsmedelsproduktionen också öka. Samtidigt behöver människans påverkan på planeten minska för att bromsa den globala uppvärmningen. Livsmedelsproduktionen skulle kunna ökas i både absoluta tal och effektivitet genom att använda matsvinn som foder för insekter. Dessa insekter skulle båda kunna användas som foder och som mat för människor, vilket påvisas av de två miljarder människor som regelbundet äter insekter. Syftet med denna studie är att undersöka insekters miljö- och näringsmässiga potential som mat och foder. Studien undersöker även hur insekternas näringsvärde och tillväxt påverkas av olika foder. Eftersom européer i stor utsträckning fortfarande känner avsmak och neofobi inför tanken på att äta insekter, är det relevant att fundera på andra sätt att använda insekter. Fiskodlingsbranschen växer snabbt i Sverige samtidigt som fiskarnas foder produceras på ohållbara sätt. Därför undersöker denna studie även insekters potential som fiskfoder. Resultaten visar att insekter är generellt sett säkra att äta för både människor och fiskar, samt är bra källor till protein, fett, kostfiber och flera mineraler och vitaminer. Många olika sorters substrat verkar kunna användas som foder för insekter, så länge näringsinnehållet i fodret är tillräckligt högt för att insekterna ska kunna leva och växa. Fettsyrasammansättningen i insekter påverkas av fettsyrasammansättningen i deras foder, medan aminosyrasammansättning inte verkar påverkas i någon större utsträckning. Fiskmjöl i fiskfoder kan med goda resultat ersättas helt eller delvis med insekter av flera arter, huvudsakligen svart soldatfluga och mjölmask. Insekter verkar kunna förbättra immunologisk hälsa och tarmflora hos fisk, och resultaten pekar på att fiskars tillväxt kan förbättras när de utfodras med insekter. Dock varierar tillväxt och foderanvändningseffektivitet mellan olika kombinationer av insekter och fisk.

Sammanfattningsvis kan insekter födas upp på många olika substrat och då producera ett näringsrikt livsmedel eller foder. Vidare forskning behövs på specifika matsvinnstyper och deras effekter på tillväxt och säkerhet för utveckling av realistiskt användbara produktionssystem. Mer forskning behövs också för att tydligt avgöra vilka kombinationer av insekter och fisk som är mest produktiva.

Nyckelord: ätbara insekter, insekter som foder, hållbar livsmedelsproduktion, fiskodling,

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Abbreviations

SLU	Swedish University of Agricultural Sciences
BSFL	Black Soldier Fly Larvae
FAO	Food and Agriculture Organization of the United Nations
WHO	World Health Organization
GHG	Greenhouse gas emissions
UN	United Nations
SFA	Saturated fatty acids
MUFA	Monounsaturated fatty acids
PUFA	Polyunsaturated fatty acids

1. Introduction

As the population of the world continues to grow while the planet does not, and while the food supply chain causes 26% of global greenhouse gas emissions (Poore & Nemecek 2018), increased efficiency in the food production chain becomes necessary. In 2021, the world population is 7,8 billion, and is estimated to grow to 10 billion in about 25 years (Worldometer 2021). Since 1990, global emissions of carbon dioxide, a greenhouse gas, have increased by nearly 50%, causing global increases in average temperatures (United Nations 2021). The global increase in temperatures is, and will be, causing reduced harvests, extreme weathers and rising sea levels, with negative ripple effects on the planet. The 2015 Paris Agreement states a common goal of limiting global warming to less than 2, preferably below 1,5 degrees Celsius and is currently signed by 197 states (UNFCCC 2021). The Food and Agriculture Organization of the United Nations (from here called FAO) report "The State of Food Security and Nutrition in the World 2020" states that in 2019, almost 690 million people were undernourished. Food insecurity at moderate levels is experienced by 1,25 billion people, 16 percent of the world population. This is described as not regularly having access to nutritious and sufficient food (FAO et al. 2020). Part two of the same report focuses on the affordability of healthy diets, and states that: "…healthy diets are unaffordable for many people in every region of the world, especially for the poor and those facing economic challenges." (FAO 2020)

A "nutrient adequate diet" (6-8 food items that meet requirements for essential nutrients and provide enough energy) though it lacks in variability, was still too expensive for people living at or below the poverty line; it cost three times as much as a simple "energy sufficient diet", which in this report was determined as the cost of one single starchy staple in an amount that covered the daily energy need of an average adult woman. Protein-rich foods are according to this report among the more expensive food items, especially in low-income countries. The prevalence of food insecurity and the evidence that healthy diets are unaffordable makes one thing very clear: the production of food with good nutritional value must increase, and it must increase in a way that is economically accessible to everyone.

One potential food source is insects, which might help satisfy the increased demand for protein, while at the same time addressing the challenges of the imminent climate crisis. To many Europeans, the idea of eating insects may seem alien. However, in many parts of the world insects are a standard part of the diet and not considered different from other foods.

Two billion people consume insects regularly (van Huis 2013), however, in Europe and Sweden, this has not been the case for a very long time. Despite this, interest in insects as food is booming, with insect farming start-ups appearing all over Europe, such as French Ÿnsect and Swedish Tebrito. Insects are generally rich in good-quality protein and fats, and several species are relatively easy to farm (van Huis 2013). One major question-mark when it comes to the sustainability of raising insects for food or feed is what feed sources they are raised on. Like with all animal husbandry, efficiency increases if the animals can be fed feedstuff that is unfit for human consumption. When we change the feed of insects, naturally one can assume that the chemical composition of the insect changes, which in turn affects its nutritional value. This report will include an investigation into the effects of using different feeds for insect farming.

According to edible insects researcher Arnold van Huis, neophobia and learned disgust prevents Europeans from fully embracing insects as a novel food source (van Huis 2013). Lack of consumption leads to a lack of funding, which slows down the pace of development within the food insect industry. One possibility for financing insect production companies in the start-up phase, is to use insects as feed for farmed fish in aquaculture systems. Aquaculture as an outlet for the produced insects would allow for development of the insect industry while use for insects as food is still in its infancy. Generally, national food guidance documents direct people to increase their fish consumption, while the national production of farmed fish in Sweden is low relative to other countries. Yet, the Swedish interest in development in this area is growing, as several Swedish research projects involving both academia and companies currently examine alternative feed sources in aquaculture (havet.nu 2020; Vidaković 2020; Kiessling 2021; cirkularodling.se u.å.) while land-based fish farming is on the rise with different enterprises currently expanding and building new farms (Premium Svensk Lax AB 2020; Gårdsfisk u.å.; Johannas Stadsodlingar u.å.). With this development in mind, this report also investigates the potential to use insects as feed for fish.

1.1. Aim

This report aims to answer several questions:

1. What is the nutritional value of insects for humans and for fish, respectively?
2. How is the nutritional value of insects affected by varying the feed source?

3. Can food waste be used to raise insects in a sustainable way?
4. Can insects be a future source of food and feed?

To give depth to the readers' understanding of the subject, topics such as legislation, safety, climate impact, food waste and consumer acceptance will be covered.

1.2. Increased global demand for protein

As the world population increases, it is natural that the global demand for protein also increases. As we aim to increase food security, it is critical that we also increase protein production.

The Recommended Daily Allowance (which covers the protein need of 97,5 % of the population) according to a report from WHO, FAO and UNU (United Nations University) is 0,83 g protein/kg bodyweight and day (WHO et al. 2002). This is a down-revised number from earlier studies; however, studies show that poor protein quality (determined by content of essential amino acids and the digestibility of the protein) is associated with stunted growth. Additionally, intakes of essential amino acids are too low in children in countries where the diet is mostly composed of carbohydrate-rich staples such as cassava and maize (Semba 2016).

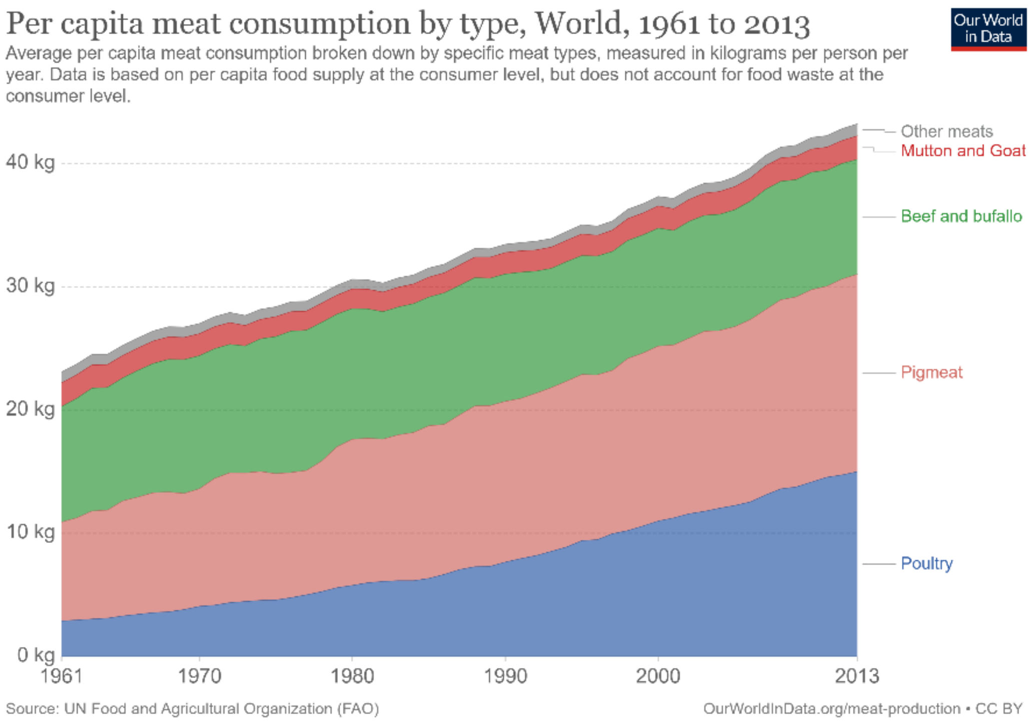

Figure 1 Per capita meat consumption by type, using data from FAO. Graph by OurWorldInData

Still, meat consumption is rising in the world (see fig. 1(Ritchie & Roser 2017)). Ritchie also writes that statistics show a strong positive relationship of how total meat consumption of a country increases when the average GDP per capita increases. In countries with rapid economic growth this is especially clear. For example, the meat consumption in China has increased by approximately a factor of 15 between 1961 and 2017. The increase in meat consumption on a global scale is not only from consumption in high-income countries, which in many cases rather have a stagnating or decreasing meat consumption. In fact, meat consumption is increasing world-wide, including in middle- and low-income countries. Apart from animal protein, vegetable sourced protein consumption is also increasing, with soy protein representing the largest share (Grandview Research 2020). Comparing population growth and different trends in protein demand (general protein demand, not exclusively animal protein), at a population of 9,6 billion people, Henchion et al. (2017) calculated estimations of future change in protein demand. If the population of the world at 9,6 billion would consume protein amounts equal to the current world average (80 g/capita/day, based on data from 2009-2011), protein demand would increase by 33% (Henchion et al. 2017). If the people representing the numeric increase in population would demand protein matching that of the richer countries in the world (103 g/capita/day), protein demand would see a 43% increase. Would the whole population of the world demand protein at the levels of the current highest consumers, demand would increase by 78 %. Interestingly, the authors point out that if the whole future world population would demand protein at levels required for sedentary adults, the global demand would instead decrease, by 13%. These calculations show that although certainly, protein demand naturally can increase with increasing world population, changing consumption patterns are also increasing the protein demand.

1.3. Climate impact of animal protein production

Current food production systems have a large impact on the climate of the Earth, with the whole food supply chain causing 26% of anthropogenic (from humans) greenhouse gas emissions, with the farm stage representing 61% of these emissions, and simply scaling up the systems currently used will increase that impact (Poore & Nemecek 2018). The 2015 Paris agreement states that emissions must decrease to a point where the global temperature does not rise more than 2 degrees (UNFCCC 2021), yet the population of the world needs food and will need more of it. The demand for animal protein is increasing rapidly in many parts of the world (Ritchie & Roser 2017). Simultaneously, production and consumption of animal products is increasingly put under scrutiny for its impact on both climate and local environment.

One key argument against the use of animal protein is the fact that very often, production of feed for animals requires the use of land that otherwise could have been used to produce food for humans, for example protein-rich legumes. Systems for producing animal feed differ widely and thus it is impossible to give an exact value for climate impact from meat. A 2018 FAO report explains the use of human-edible food as feed, showing that 14 % of global livestock feed intake (dry matter) consists of such substrates (Mottet et al. 2017). Human-edible food is such things that would have been suitable as food for humans. This means, 86% of global livestock feed intake is not edible for humans. With that in mind, the authors of the report calculated the amount of human edible food used as feed to produce 1 kg of boneless meat (within the OECD). These values are given in table 1.

For fish, it is more difficult to calculate the human edible portion of the feed. Typically, a fish feed used for salmonid fishes contain, in different ratios (and not always all ingredients), fish meal and fish oil, and vegetable ingredients such as wheat, rapeseed oil, soy or corn (Svenskt Vattenbruk 2020). Wheat, rapeseed oil, soy and corn may all be considered human edible although that greatly depends on their quality. 10-25 % of the material for fish meal are offals or residual meat pieces left on the bones after slaughter, with the remainder coming from fish that are discarded from wild fisheries, due to small size, bad taste, or high content of bones.

The general argument is that these discarded fishes that are used to produce feed are not edible for humans. However, a 2017 study found that as much as 90 % of the wild caught fish currently used for feed is of food grade (Cashion et al. 2017). In the report The State of World Fisheries and Aquaculture 2020 (FAO 2020), it is shown that currently 34 % of the world's marine fish stocks are overfished, an increase from 10 % in 1974. In conclusion, fish feed could generally be seen to be composed of human edible substrates (see table 1), and the demand for fish meal and fish oil are currently contributing to overfishing.

Concerning feed for insects, within the EU they can generally be raised on similar feedstuffs as other livestock and are covered by the same feed legislation. Naturally, a certain amount of feed produced will cause the same climate impact regardless of which animal consumes it. Thus, the feed production of an insect farming system will be equal in climate impact to other animal production systems that uses the same feed. A standard feed for mealworms (used as example in table 1) is a combination of grains and carrots, depending on the grain type, 100% of that feed could be considered human edible.

Table 1 Feed conversion ratios and climate impact of livestock. Feed conversion ratio is the amount of feed (in kgs) required for 1 kg of growth, based on how much human edible food is necessary. CO2-eq/kg edible meat is one way to express climate impact.

	Mealworm	Pig	Chicken	Beef	Salmonid fish
Human edible food FCR	2,2 (Oonincx & Boer 2012)	4,0 (Mottet et al. 2017)	3,6 (Mottet et al. 2017)	3,9 (grazing, Mottet et al. 2017) or 6,0 (mixed, Mottet et al. 2017)	1,0-1,1 (Bailey 2018)
Edible percentage of body weight	100% (Halloran et al. 2018)	62 % (Röös 2014)	76 % (Röös 2014)	35 % (Strid et al. 2014)	70 % (Mireșan et al. 2012)
Kg CO_2 eq/kg edible meat	2,7 (Oonincx & Boer 2012)	5,5 (Röös 2014)	2,5 (Röös 2014)	26 (Röös 2014)	3 (Röös 2014)

Most animals are not fully edible, and have parts that aren't fit for human consumption. This has an impact on the resources needed to produce food for humans, as feed conversion ratio only considers the whole-body growth. With the same feed conversion ratio, an animal with a larger edible percentage of body weight will be more efficient than an animal with a lower edible percentage of body weight. The carcass weight is the weight of the animal after skin, offals, head, feet, genitalia etc are removed, however bones remain. Slaughter yields are usually calculated as the carcass weight divided by the live weight. Slaughter yields for beef are estimated at 50 % (Strid et al. 2014). The edible portion of the carcass weight is 70 % for beef. This gives a percentage of edible meat per total body weight of 35% (70% out of 50% of the animal). Drawing from calculations of climate impact based on *carcass weight* (Cederberg 2009), Röös calculated the impact based on *edible weight* in the report "Food-climate-list 1.1" (Röös 2014). These calculations by Röös are presented in table 1. For beef, the average of 26 CO2-eq/kg edible meat represents an average of Swedish production systems. Röös discusses an interval of 17-40 CO2-eq/kg which ranges from intensive production of animals originating in the dairy industry to the high-impact extensive rearing of meat cattle, for example in Brazil. The variations in pork and poultry production systems are smaller, with the impact from pork ranging from 4 to 8 kg CO2-eq/kg edible meat, and the impact from poultry ranging from 1,7-4 kg CO2-eq/kg. Slaughter yield of fish (exemplified by salmonids, commonly farmed fish) when all viscera, head, bones, fins, skin and scales are removed (to yield a pure fillet) is 70 % (Mireșan et al. 2012). According to Röös (2014) 3 kg CO2-eq per kg edible fish is an estimate that can apply to both farmed salmon and wild-caught cod, while wild-caught herring and mackerel can cause below 1 kg CO2-eq per kg edible fish.

In a life cycle analysis of mealworm production, mealworm production was calculated to produce 2,7 kg CO_2-eq/kg mealworms (see table 1). 42 % of the 2,7 kg co2-eq/kg mealworms was attributed to production and transport of feed grains and 14% to production and transport of carrots (Oonincx & Boer 2012). Insects do not consume energy to produce body heat as they are cold-blooded (body temperature equals ambient temperature), which makes them more efficient in using the calories in feed for growth. Also, generally the whole insect is edible. This means that feed conversion ratio alone, does not give a full picture of the feed required to produce a kilogram of edible food. In the results part of this report, consequences on growth for insects fed experimental diets will be explored.

Feed production climate impact can be related to several factors, of which a very important one is deforestation. Protecting forests is seen as one of the more important factors in mitigating climate change, as forests sequester large amounts of carbon, as well as providing many important biosystems services (Theurl et al. 2020). Deforestation increases when the demand for animal feed increases, it is thus important to consider the effects of animal feed farming.

Water consumption in insect farming is relatively low compared to other animal production systems. Some insects may require a specific water source (e.g. crickets), others get the water they need from either a moist substrate (e.g. black soldier fly) and yet others get water from an added substrate (e.g. carrots used for mealworms) (Oonincx et al. 2015). Thus, water consumption required for the whole process of rearing insects can be mostly attributed to the production of feed. One calculative study found that the water consumption based on edible weight was similar between mealworms (4341 m^3/edible ton) and chicken meat (4325 m^3/edible ton), while pig meat required on 5988 m^3/edible ton and beef 15,415 m^3/edible ton (Miglietta et al. 2015). When the water consumption was instead calculated based on protein content, mealworms consumed 23 litres/g protein while chicken meat, pig meat and beef meat consumed 34, 57 and 112 litres/g protein respectively.

Electricity consumption for heating can be a concern for insect farming. One example is mealworms which require temperatures between 25 and 32 degrees Celsius for ideal growth (Rueda & Axtell 1996). Energy used for heating is a large contributor to the environmental impact of insect farming, especially in colder climates. In the previously mentioned LCA of mealworm production in the Netherlands, 26 % of the Co2-equivalents came from the gas used for heating (Oonincx & Boer 2012) . If the farming system is placed in a tropical country this is of less concern. Insect farms could potentially be placed in connection to businesses that produce excess heat, such as server halls. This would reduce the CO_2-eq impact by 0,7 CO_2-eq/kg mealworms down to 2,0 CO_2-eq/kg, based on the LCA.

1.4. Food waste

In discussing, managing, and researching food waste, semantics are of importance. Some definitions of food waste include only food which was suitable for human consumption but was discarded by consumers. Other definitions expand the concept of food waste to also include pre-consumer waste, such as discarded produce in supermarkets or food which passes its best-before date before it reaches a consumers' plate. Yet further, the concept of food waste can be expanded to include waste from the food industry, such as damaged products that are discarded, or even to include on-farm waste such as produce left on the field for reasons like aesthetics or size differences. Where the line is drawn may seem unimportant for the general goal of reducing food waste. However, plenty of resources are lost in every step of the food chain, resources that might be put to better use. The UN uses two definitions, food loss and food waste. Food loss refers to the food that is lost before the retailer step (and not used as feed), while food waste is food lost at retailer, food service providers or consumers (FAO 2021b). In this report, no set definition of food waste is used. Rather, the investigated types of food waste are described and categorized as the source material categorizes them. In the discussion, food loss and food waste will be used interchangeably.

Halving the amount of food wasted is one of the UN 2030 Agenda goals. In March 2021, the UN released a report which estimated that 17 % of all consumer-available edible food, 931 million tonnes, was wasted during 2019. This would account for food wasted in households, grocery stores, restaurants, and similar places, but does not include pre-consumer waste such as on-farm or in industry settings. The report also estimates that 8-10 percent of all greenhouse gas emissions are associated with food waste, claiming that if food waste was a country, it would the third largest greenhouse gas emitter in the world. Eleven out of the previously mentioned 17% wasted food originates in households. Clearly, if one is interested in reducing human impact on the climate of the Earth, food waste is an area that needs exploration.

Food waste management and legislation differs widely throughout the world. The EU countries, Sweden being one of them, have committed to meeting the UN 2030 Agenda goal of reducing per capita food waste by 50%.

Swedish consumers discarded 917 000 tons of food as waste in 2018 (see fig. 1) (Swedish EPA 2020). It is important to distinguish, that these calculations only consider the food that is discarded as waste products. It does not include products from the food industry such as blood, dough waste, bread and crackers and packaged dairy. Neither does it include many other sources of food waste that currently are used as animal feed, and there is no official data currently available measuring this.

In Sweden, household food waste is usually disposed separately from other waste, and used to produce biofuel. It is also required by law that restaurants sort their food waste (Stockholm Vatten och Avfall 2016). The biofuel is used as fuel for cars, and the mass that is left over after fermentation is used as fertilizer on fields. Certainly, the production of biofuel and fertilizer is one way of using the carbon in food waste for something constructive. Still, biofuel is "single-use" as the burning of the gas causes emissions of carbon dioxide to the atmosphere which is then "lost". Researchers argue that this loss is avoidable by using food waste to produce new food, for example by feeding it to insects that can be consumed as food or used as animal feed, so called "bioconversion" (Fowles & Nansen 2020). The effects and potentials of using food waste as insect feed will be covered in the results part of this report.

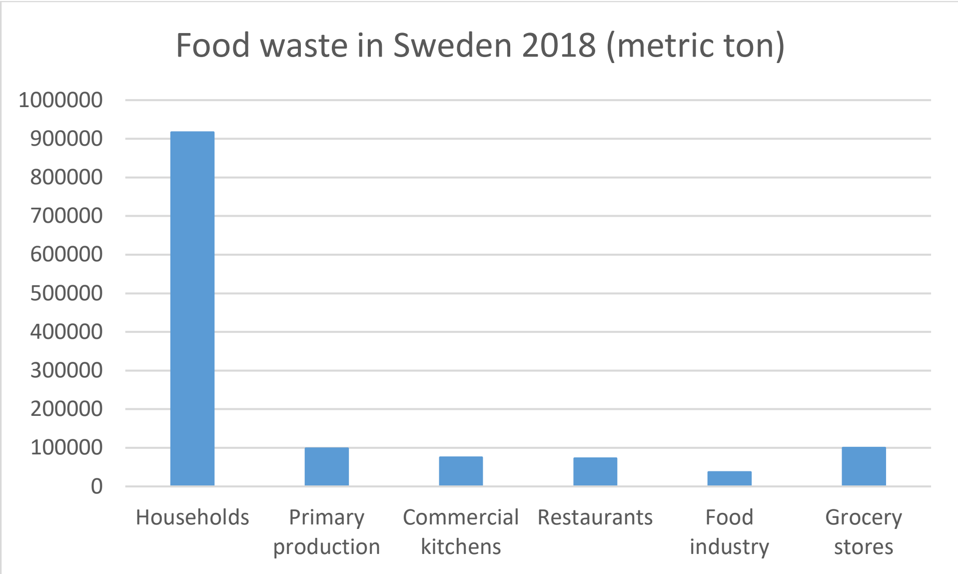

Figure 2 Food waste in Sweden, data from the Swedish Environmental Protection Agency.

Food waste can be used to rear animals, however European legislation formed after the bovine spongiform encephalopathy or "mad cow disease" outbreak sets strong boundaries on which food waste can be used as animal feed. Bovine Spongiform encephalopathy was a disease that spread through livestock after dead, sickly cows had been used as feed for other cows. Feeding animals with other animals of the same species carries the risk of cycling back disease into living animals, and crosses ethical boundaries as well. European Commission regulation 999/2001 limits the use of ruminant-source feeds to dairy, gelatin or certain hydrolyzed proteins (European Parliament & Council of the European Union 2001). EC regulation 1069/2009 specifies other types of animal products that may be used as feed; milk, eggs, honey, rendered fats, fish meal, fish oil and certain heavily processed animal proteins (European Parliament & European Commission 2009). The processing or separation required to use animal-source resources as feed heavily reduces the possibility of sourcing food waste for use as feed from consumers, as consumer food waste usually is a mix of vegetal and animal-source foods. Use of food waste containing any animal products as feed is prohibited according to EC regulation 1774/2002 (European Parliament & European Commission 2002).

1.5. Insect farming

Although insects have been used as food all over the world for millennia, farming insects for human consumption is relatively rare. Bees and silkworms have been kept for thousands of years (Encyclopedia Britannica 2020; Chadefaud 2021), as humans are interested in materials they produce (honey, beeswax, silk). However, these insects themselves are not routinely consumed as food. Beehives, bee products and silk production (silkworm cocoons and silk) are also the only insect products currently tracked by the FAO database FAOSTAT, which makes it difficult the scale of worldwide insect production (FAO 2021a).

Despite not showing up in most official documents, some insect farming does still occur. In Thailand, insect consumption is relatively common and over 20 000 cricket farming enterprises were registered as of 2013 (Yupa Hanboonsong et al. 2013). Entomologists at Khon Kaen University in Thailand developed technology to farm crickets and spread this across the country, including introducing small-scale cricket farms in schools. In the beginning, only cricket species native to Thailand were farmed, but these have largely been replaced by the house cricket (*Acheta domesticus*) owing to its better taste. The crickets are commonly fed commercial chicken feed.

1.6. Insects as food

1.6.1. Disgust, neophobia and neophilia

When discussing the consumption of insects as food, one cannot bypass the question of whether insects are to be regarded as food at all. As previously stated, two billion people consume insects as food with relative regularity. We can thus conclude that insects *can* be considered food. Yet, many people would view the consumption of insects as food with disgust. It is in this context that we can benefit from exploring the concepts of disgust, neophobia and neophilia. Disgust developed in our ancestors to "facilitate the recognition of objects and situations associated with risk of infection (…)" (Curtis 2011). As such, it is natural to occasionally experience disgust, however as Curtis (2011) argues:

> Disgust is an adaptive system whereby individual responses vary according to an individual's personality and learning experience, as well as by local cultural effects such as norms about manners and the symbolism of pollution and purity.

Thus, a person’s triggers for disgust might vary and, in the case of eating insects, may be completely non-existent in individuals that are accustomed to this practice. So, how about the people who are not accustomed to eating insects? What are their reactions? Certainly, disgust might be one. Neophobia and neophilia may also occur.

Neophobia is the fear of new things, and food neophobia specifically refers to the fear of eating new foods (Dovey et al. 2008). Food neophobia naturally occurs in most small children, and gradually decreases with age. In some adult individuals, food neophobia may cause severely restrictive eating patterns (Marcontell et al. 2003). However, a certain fear of trying entirely new foods generally persists throughout life. It may be exacerbated by cultural influences (mainly, lack of cultural exposure to food groups) as exemplified by general food neophobia towards unfamiliar, imported foods in some senior citizens (Dovey et al. 2008). It is natural that individuals who grew up and live in an environment with no traditional consumption of insects may be neophobic towards insects as food. However, as Dovey (2008) argues, there is an important distinction between food neophobia (unwillingness to try new foods) and rejection of the food once it has been tasted and the novelty is removed. Rejection of familiar foods would thus come from unpleasant eating experiences. A study examining the factors influencing willingness to eat familiar and unfamiliar foods found that willingness to consume familiar foods is driven by anticipation of good taste and pleasure, while willingness to consume unfamiliar foods is mainly determined by perception of disgust (Martins & Pliner 2005). This would also seem to apply to insects, with studies showing that motivations differ between initial and regular consumption of insects. One study investigating these motivations examined the different attitudes toward insect consumption in Thai and Dutch consumers. Dutch consumers motivated their consumption of insects with novelty, and with an interest in environment and nutrition. They had less familiarity with the taste of insects, and less knowledge about cooking methods, compared to Thai consumers. Thai consumers that regularly eat insects do so because of good taste, while also expressing strong preference for local foods and dislike for unknown foods (Tan et al. 2015). These Thai consumers can thus not be regarded as neophiliac.

Food neophilia is the seeking out and enjoyment of new food experiences, often in connection to travel or social eating (Okumus et al. 2021). The previously mentioned Dutch consumers were described as novelty-seeking, an example of how neophilia can support consumption of insects. An example of how insect consumption might be framed as novel food to interest neophiliac consumers is to advertise them as “land-seafood”, as insects and crustaceans belong to the same phylum, arthropods.

1.6.2. Tradition, changes

Across the world, traditional insect consumption is often small-scale, based on wild insects, prepared in a home setting, or sold in markets. This section will give some examples to provide a perspective of how commonplace insect consumption really is across the world, and how the consumption patterns are shifting.

South Korea has a traditional history of eating rice grasshoppers as well as silkworms. In the 1970’s, the South Korean government deployed a strategy to stimulate the economy by industrialization. As industry became more important economically and competed for land with the less profitable agriculture, agricultural activities in Korea drastically decreased. With the decrease of farmland available, the availability of insects decreased too (Halloran et al. 2018). This all led to fewer children having access to insects as a regular part of their diet. Combine the lower availability of food insects with the impact of Western cultural ideas and Korea now has a generation gap where older generations see insects as food while many in the younger generations consider insects with disgust (Han et al. 2017).

Mexico is another example of a country that has a long history of insect consumption, echoing through to present-day restaurants and delicacies. Especially in the Oaxaca region, traditional ways of foraging for and cooking insects like chapulines (grasshoppers of the genus Sphenarium) are still practiced (Cohen et al. 2009). Most insects consumed in Mexico are gathered from the wild.

One still practiced European example of traditional insect consumption is the cheese Casu Marzu, a sicilian goats milk cheese that contains live larvae. After the cheese is formed, cheese flies (*Piophila casei*) lay eggs in the cheese, which hatch into larvae. These larvae feed on the cheese which, according to chapter author Luca Manuza in the book Edible Insects in Sustainable Food Systems, affects the ripening and contributes to flavour development, while the larvae themselves also have a special taste and texture (Halloran et al. 2018). Sale of Casu marzu is forbidden in Italy, as authorities deem the process of making these cheeses unsafe. Still, Casu marzu can be found for sale online. Similar cheeses also have a history in other parts of Italy, as well as Greece and Turkey.

One place where traditional consumption has continued to present day is Thailand, where insects fetch a higher price than many other types of meat and are consumed all over the country, including both rural and urban consumers across all economic classes (Yupa Hanboonsong et al. 2013). Giant water bug (*Lethocerus indicus*) and several species of grasshoppers are gathered from the wild and eaten across the country seasonally, while other species such as palm weevil larvae and are consumed in the areas where it can be farmed. Edible insects are also imported to Thailand in large amounts, Hanboonsong et al. refer to estimates claiming import volumes of 800 tonnes edible insects annually.

1.6.3. Legislation

The EU previously categorized insect-based foods as novel food, subject to safety analysis before being allowed on the EU market. However, several European countries have taken the matter into their own hands and legalized insects locally. In 2017 Finland decided to interpret the EU law on novel foods to not include whole insects, and thus allow whole insects to be sold as food (Buchert 2017). In October 2020, a European Union Court of Justice ruling declared food made from whole insects as not falling within the definition of novel foods, effectively admitting whole insects (or products made from whole insects) to be legal as food within the European Union (Wahl et al. 2020). In January of 2021, the EFSA released a statement declaring dried mealworms to be considered safe (EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA) et al. 2021). Although interested pioneers have been able to order insect products internationally, the decisions from the EU make life easier for insect producers and open the market to product development in a whole new way.

In countries with traditional insect consumption, insects may not always be separately covered by legislation as they are subject to the same general legislations on safe food production as any other food (Halloran et al. 2015). Halloran et al. (2015) argues that apart from food safety, legislation should also consider issues such as nature conservation (particularly in areas with wild forage of insects), traditional food culture, food security and potential economic development. Food security was also one of the factors influencing the Finnish decision in 2017 to allow insects, as the state wanted to promote food security-increasing developments (Buchert 2017).

1.7. Nutrition in fish consumption

In this section, the nutritional advantages of fish consumption will be described, to give a base to the reasoning of using insects as fish feed. In most national food guidance documents, fish is touted as health-promoting and increased consumption of fish is recommended. The Swedish Food Agency recommends eating fish two or three times per week (Swedish Food Agency 2020a), while the British NHS guide “The Eatwell Guide” recommends at least two portions of fish every week (NHS 2019). The Dietary Guidelines for Americans 2020-2025 state 8-10 ounces (about 225- 280 grams) as recommended weekly intake, depending on body size (U.S. Department of Agriculture & U.S. Department of Health and Human Services

2020). Some studies indicate that intake of fish can be associated with lower risk for disease. A 2006 review of studies on fish consumption and health outcomes found “modest” consumption of fish (1-2 servings/week) to reduce risk of coronary death by 36% and total mortality by 17% (Mozaffarian & Rimm 2006).

The general reasoning behind the fish intake recommendations is based on health-promoting effects of fish as food in general, as well as the evidence that omega-3 fatty acids EPA and DHA carries special importance in nutrition. In the 1970’s, studies on diet and health in Greenland Inuit claimed a connection between their omega-3 intake and good health (Bang & Dyerberg 1972). This strongly contributed to the idea of omega-3 as health promoting. However, more recent studies have shown that the incidence of cardiovascular disease is not lowered in Inuit populations (Bjerregaard et al. 2003). Some argue that the 1970’s studies by Bang and Dyerberg have been, and continue to be, routinely misinterpreted and over-interpreted, owing to the “limited validity” of the health data that was used (Fodor et al. 2014). According to more recent health data, Greenland Inuit have higher risk of stroke and 10 years shorter life expectancy than non-Inuit Europeans. Fodor et al. postulate that potential positive health effects of fish consumption may relate to its content of the amino acid taurine, which has been connected to lower mortality in coronary heart disease. In any case, Inuit diet would not generally be seen as health-promoting, with low content of vegetables and other important nutrients. Fodor et al. conclude their review by saying that although most health recommendations encourage fish intake, and fish oil production is a billion-dollar industry, it is based on a hypothesis which was “questionable from the beginning”.

The clinical study VITAL examining the effects of omega-3 supplementation (fish oil) on risk for major cardiovascular events and invasive cancers found no difference for general population in risk between groups given a omega-3 supplement or a placebo (Manson et al. 2019). There were however significant reductions in risk for both major cardiovascular events (-19%) and myocardial infarction (-40%) when supplemented with omega-3, for the groups with below-median consumption of fish (<1,5 servings/week). When commenting on these findings, study lead author JoAnn E. Manson argued that fish consumption may occur in place of “less healthful foods (…) such as red meat, processed foods or refined grains” (Harvard Health Publishing 2019).

Yet, a large Cochrane review of omega-3 supplementation, including meta-analysis that included the VITAL study data found little or no effect on risk for all-cause, CVD or CHD mortality or CHD events (Abdelhamid et al. 2020). Fish consumption did not seem to significantly affect risks, although few studies examining the effects of dietary fish intake were included and thus “our ability to assess effects of eating more oily whole fish is limited” (Abdelhamid et al. 2020). They claim fish to be a good food source, even if it lacks cardiovascular benefits, as they are nutrient-dense and rich in vitamin D, calcium, iodine, selenium, and protein, and may displace less nutritious foods. The authors also point out that epidemiological studies showing higher fish intake correlating with lower CVD rates could be largely confounded by dietary quality, socioeconomic status, and other markers of healthy lifestyle. Still, research indicates that long-chain polyunsaturated fatty acids (EPA and DHA) are “of importance for neurodevelopment and neuroprotection” in infants, with both the intake of the mother during pregnancy and the child after birth being of importance (Klevebro et al. 2020). Thus, although a higher fish consumption can be correlated with good overall health, it is impossible to attribute that singularly to the omega-3 contents, and fish consumption can be motivated by its content of other nutritious components although a higher omega-3 content in fish should be seen as beneficial.

2. Materials & Methods

2.1. Literature study

This project was performed as a literature study, with the aim of investigating current scientific knowledge in the areas of food waste, insect farming, insects as food and insects as feed. Also, to converge these findings into answers to the overarching questions of this report; can insects be a sustainable source of food and feed, and can they be raised for those purposes on feeds made from or containing food waste?

To give a solid base in the subject of insect rearing, the excellent book “Edible Insects in Sustainable Food Systems” was included. This book comprises short articles by many researchers in different fields, giving insight into different perspectives on insects as food and feed. Larger publications from the United Nations Food and Agriculture Organization (FAO) were also read early in the project to give a broad insight into the field, names of leading researchers and new perspectives on interesting paths to investigate further.

Literature was mainly found through searching for relevant terms in the SLU library’s databases and Google. Many sources were discovered by browsing the references and citations of relevant scientific articles. Also, literature was found by reading other articles by researchers investigating especially interesting areas. Studies with experimental designs deemed irrelevant for the purpose of this report were excluded. Detailed genomics research on fish raised on insects is one example of this. When searching for literature, studies from more recent years were prioritized. As the field of insect as food or feed is relatively new, although it currently sees rapid growth, most studies found were from the year 2000 or later with a large number of studies from the last five years. The size of the field was also made clear by how often names of some researchers appeared. Some teams of researchers include; the lab of Entomology at Wageningen University, the research group on insects as food and feed at the University of Copenhagen and the research group on insect meals in animal feeds at the University of Turin. Some often-appearing names of researchers include Afton Halloran, Arnold van Huis, Laura

Gasco, Manuela Renna, Nanna Roos, Lars Lau Heckman, Jeffery K. Tomberlin, Wendy M. Sealey and Sophie St-Hilaire, among many others.

The use of insects as feed for other animals was excluded from this report. The most important reason for choosing fish as focus area is that ingredients in feed for farmed fish currently is a highly disputed subject, the use of marine fish meal in fish feed formulas being questionable in both ethics and sustainability. The reasoning behind excluding other animals was simply the size of the project and time constraints.

Search terms included were: mealworms, black soldier fly, insects as food, insects as feed, food waste, insects and food waste, insect consumption, insect food products, locusts, grasshoppers, fish feed, fish farming, crickets, insect nutritional composition, insect farming,

3. Results & discussion

3.1. Different feeds used for insect farming

Many studies have previously investigated effects of varying substrates used as feed in insect production. Several factors are of interest. It is relevant to know how well the insects grow and survive on different feeds, but also how their final nutritional composition is affected by the feeds. The potential sources of feed for insects are innumerable, one study even showed that mealworms accept Styrofoam as food and are able to degrade it (although granted, they did not grow much!) (Yang et al. 2015). This section presents current research on the effects of feeding insects with various substrates.

One large study examined forty-four different commodities as oviposition (feed for adults laying eggs) and feeding substrates for mealworms (*Tenebrio molitor*): "cereal flours and meals, non-flour, cereal commodities, legumes and various commodities of vegetative and animal origin" (Rumbos et al. 2020). Results showed that legumes gave fewer offspring, while cereal-based substrates gave larger offspring groups. Substrates with higher protein content generally gave a higher protein content in the larvae.

Common farm weeds *Commelina benghalensis*, supplemented to commercial chicken feed, were found to significantly increase body weight and decrease bacterial spore counts in the field cricket *Gryllus bimaculatus*, compared to crickets fed only chicken feed (Ng'ang'a et al. 2020).

In a study on house crickets (*Acheta domesticus*), a diet composed of only red clover in different preparation formats gave a lower body weight and higher feed conversion ratio compared to crickets fed a control diet, however survival was not different between the groups from hatching to 25 days old (Vaga et al. 2020).

Not just any feedstuff may be suitable, and processing may be required to enable use of different feeds. A study testing *okara*, a soybean waste product from production of tofu and soy milk, and bok choy as feed for house crickets (*Acheta domesticus*) found that whether mixed with each other or supplied alone, both had a negative impact of decreased growth and survival compared to crickets that were also supplied dog feed (Quek et al. 2020). The authors of this study argued that the decreased survival and growth for crickets fed *okara* might be caused by the anti-nutritional factors contained in *okara* such as trypsin inhibitors, saponins and lectin. Trypsin inhibitors decrease protein digestion, saponins reduce palatability and lectins inhibit nutrient absorption in the gut. To lower the content and effect of these anti-nutritional factors, the authors suggest processing such as fermentation or additional boiling. The negative effects of the bok choy were attributed to possible contents of anti-herbivore glucosinolate compounds found in Brassicaceae plants. Glucosinolate compounds give a bitter taste, and may be toxic to insects (Furlan et al. 2010).

Lundy and Parrella showed in a 2015 study that the quality of feed for insects is of utmost significance for survival, growth and feed conversion ratio. Lundy and Parrella compared the following five trial feeds for house cricket (*Acheta domesticus*) (Lundy & Parrella 2015):

1. A mix of poultry feed and rice bran (control)
2. The "solid, pasteurized, post-process filtrate from a proprietary, aerobic enzymatic digestion process that converts grocery store food waste into 90% liquid fertilizer and 10% solids (the portion used in the experiment)" (Food Waste 1-FW1)
3. Minimally processed, post-consumer food waste
4. A 1:1 ratio of wheat and maize silage containing approximately 50% non-grain aboveground biomass (straw)
5. A 2:1:1 ratio of poultry manure, wheat straw and rice straw silage

The feeds and the experimental setting (large-scale, high density-populations) were chosen to represent realistic scenarios. The study showed that the crickets fed the control diet gained 4574 % biomass (in fresh weight) while the crickets fed diet 2 had a 2583 % weight gain, both groups with high survival rates. The crickets fed feed 3, 4 and 5 had extremely poor survival, all reaching 99 % mortality. Based on the experimental results, authors describe a feed quality index, where the feed quality is described by the proportion of nitrogen to acid detergent fibre content plus proportional crude fat content. Feed conversion ratios of 1,7 and 2,3 were calculated for the control and feed 2 (kg dry feed/kg edible weight). The authors argue that although feed conversion efficiency was lower for feed 2, this might still be the more sustainable option as it uses organic side-streams of food waste, instead of directly supplied grain. The authors conclude that the nutritional quality of the organic side-streams used for feed will be paramount in determining the efficiency of large-scale production (titling the study "Crickets are not a free lunch") and note that the required quality of the feed may differ between different insect species and so different species may be used for different waste streams.

Another study examined the effect of using different organic waste substrates as feed on the nutritional composition of black soldier fly larvae, examining four substrates; chicken feed (as reference), vegetable waste, biogas digestate and restaurant waste (Spranghers et al. 2017). The vegetable waste was in this case composed of carrots, peas, salsify, and celery. "Biogas digestate" used as substrate was the solid filtrate from biogas fermentation of the same vegetables. The restaurant waste contained potatoes, rice, pasta and vegetables, and no animal products. Interestingly, although protein content was "highly variable" between the substrates, results showed that the protein content and amino acid composition of the larvae differed little between the treatments. However, the development time differed, from 12,3 days to the appearance of the first prepupae (a developmental stage following the larval stage) to 15,0; 15,5 and 19,0 days respectively. When fat composition was analysed, C12:0 dominated, regardless of the contents of C12:0 in the different substrates. The authors argue that this fatty acid could have advantages of quicker metabolism and better impact on gut microbiota when used in feed, compared to long chain fatty acids. However, the high total content of fat in the larvae might be disadvantageous for using the whole larvae as feed. Spranghers et al. suggest that if the lipids are partially separated from the larvae meal, the larvae meal could still provide improved feed composition but with lower fat content, while extracted lipids could be used for example to produce biodiesel.

3.1.1. Marine substrates

From the perspective of both food and feed quality, and waste management, organic waste from marine sources is of special interest. Farming fish for food gives rise to slaughter waste. Oceanic fishing generates both slaughter waste and whole fish waste, that is, fish that is discarded because of low economic value (Barroso et al. 2019). Additionally, projects like the Blue Baltic Growth project want to farm mussels for their ability to remove nutrients in an attempt to reduce eutrophication in the Baltic Sea (SUBMARINER Network for Blue Growth u.å.). These mussels would need to be part of a production chain to be economically viable, and one possible outlet is to use them to produce feed. All these sources of marine waste must be managed somehow, and one current research area is the possibility of using it to feed insects. Of particular interest is the possibility to produce insects that contain eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), as they are generally viewed as important for nutrition. The following section will describe experimental results from tests on feeding insects with different materials, with extra focus on the impact on insect fatty acid composition.

Black soldier fly larvae fed fish (*Sardinella aurita*, discarded due to low commercial value) gained significant amounts of EPA & DHA (Barroso et al.

2019). Fatty acid composition analysis of the larvae meals revealed that the DHA content increased from 1,53% in the control to 4,94% of total fatty acids in the larvae that had fed on fish for 12 days. EPA increased markedly from being undetectable in the control, to 7,2 % of total fatty acids after feeding on fish for 12 days. Authors pointed out that with these levels of DHA and EPA, 150 g of larvae meal would cover the daily needs of these fatty acids of an adult human. The content of EPA was thus similar to the EPA contents of rainbow trout or Atlantic mackerel.

Another study compared the effects of inclusion of either salmon oil or microalgae in feed for black soldier fly larvae. Salmon oil increased contents of ALA, EPA and DHA in the larvae without negative effects on growth or survival, while microalgae led to increased contents of ALA and EPA but decreased both growth and survival and did not increase DHA contents (Erbland et al. 2020).

An article written within the frame of the Blue Baltic Growth project where black soldier fly larvae were fed several substrates compared their fatty acid composition (Ewald et al. 2020). It was found that higher amounts of EPA and DHA in substrates produced larvae with higher contents of these fatty acids, although higher amounts in substrates also caused a lower relative retention as more of EPA and DHA ended up in the larval faeces (Ewald et al. 2020). However, the content also decreased with increasing larval weight. This means that smaller larvae contained more EPA and DHA, but the percentage of EPA and DHA decreased as the larvae grew. Therefore, the authors argue that larvae meal or larvae oil from black soldier fly larvae are unsuitable for replacing fish oil in fish feed. Although a higher percentage of EPA and DHA could be gained by harvesting the larvae at an earlier stage, the authors point out that this would not automatically give a higher total amount of EPA and DHA as the total weight of the larvae would be lower. Also, harvesting earlier would mean less effective use of the substrate. Ewald et al. concluded that the fat from black soldier fly larvae may not be effectively modifiable in a way that makes this a viable source of DHA and EPA for fish feed, and that it may be more suitable as replacer for vegetable oils in production of food, feed, and biodiesel.

A study examining the effect of different seafood wastes on the growth and survival of black soldier fly larvae found that although larvae grew to a large size on crab meal, survival was lower compared to other tested substrates, while larvae fed wet sea cucumber had a survival almost six times as high (Villazana & Alyokhin 2019).

One study used brown algae, *Ascophyllum nodosum*, commonly found in the north Atlantic (Liland et al. 2017). Brown algae was fed to black soldier fly larvae, which were shown to gain increased content of EPA, iodine and vitamin E, although the contents of EPA were quite low (max 1% of total FA). However, when the proportion of brown algae in feed exceeded 50%, larval growth and survival decreased. Thus, black soldier fly larvae contents of EPA may be slightly increased by use of brown algae, however it cannot be the sole substrate for optimal growth.

Another study on *A. nodosum* found a maximum of 50 % inclusion in black soldier fly larvae feed, above which the inclusion negatively affected growth and survival (Biancarosa et al. 2017). However, the larvae were found to accumulate cadmium, lead, mercury and arsenic from the seaweed, in increasing amounts when more seaweed was included in the feed. Especially cadmium was accumulated, with a retention of 70-93% of cadmium in the feed. Cadmium is described as similar in size to calcium ions, and thus can pass through cellular cadmium channels in the insect cells. Furthermore, owing to a high content of complex, metal-binding polysaccharides, seaweeds tend to accumulate metal from their environment. For lead and mercury, 10% of contents in feed were accumulated, while 6% of arsenic was accumulated. Lead and mercury contents were below EU maximum levels for use as feed. Cadmium and arsenic levels, however, exceeded the EU maximum levels allowed for complete feed, thus "including seaweed in the insect feeding media could potentially limit the use of BSF larvae as the sole component of the diet (of the fish, authors note)" (Biancarosa et al. 2017). Also, as cadmium is mainly found in the insect body and has high affinity for protein, it would likely end up in an isolated insect protein product.

3.2. Potential of using food waste in sustainable insect production

Feed production is an important source of greenhouse gas emissions in insect production (Oonincx & Boer 2012). Research presented in the previous section indicate that various substrates may be used as feed for insects in a climate-friendly manner, including pre- or post-consumer waste. However, care must be taken to a) provide good nutrition for the insects, b) not cause spread of disease through animal-source substrates, c) follow current regulations on feed use, and d) not use substrates that compete with human consumption. In comparison with other types of animal meat, insects seem to have lower or equal climate impact, lower water consumption and less space requirement (Oonincx & Boer 2012). Designing systems with effective energy use is paramount in reducing the carbon footprint as heating represents a significant portion of the climate impact of insect production (Oonincx & Boer 2012).

In comparison with vegetable protein sources, climate impact is equal or slightly higher for insects at 2,7 kg CO2eq/kg mealworms, (Oonincx & Boer 2012). Röös (2014) presented climate impacts of 0,2-2 kg CO2eq/kg legumes, 1-6 kg CO2eq/kg for vegetarian meat substitutes and 4 kg CO2eq/kg for quorn. To give a more nuanced picture, life cycle analysis should in the future be performed on more insect species and different production settings.

3.3. The value of insects as food

3.3.1. Nutritional composition

Not all insects have the same nutritional composition, which is only natural given the wide range of species considered edible. Just as the nutritional composition is not the same in beef as in pork, differences can also be found between different insect species. This section will provide an overview of nutritional composition in insects, as described by Rumpold and Schlüter in their large 2013 review of studies on insect nutritional composition. The nutritional value for humans is evaluated throughout this section.

Rumpold and Schlüter compiled the data from 236 nutrient composition analyses, and found that in general, insects are good sources of energy, protein, fat, minerals and vitamins, see fig. 3 (Rumpold & Schlüter 2013). Data presented in this figure includes the full range of life stages for insects, including e.g., larvae and beetles. Thus, it can be expected that some parameters can be both higher and lower for a specific species in a specific life stage, as for example larvae often are higher in fat. Protein is the main nutritional constituent of most insects, all evaluated orders of insects had average protein contents (on dry matter basis) above 35%, with some orders averaging higher still. The order Orthoptera (grasshoppers, crickets, locusts) had an average protein content of 61,32% with certain species reaching above 70% protein.

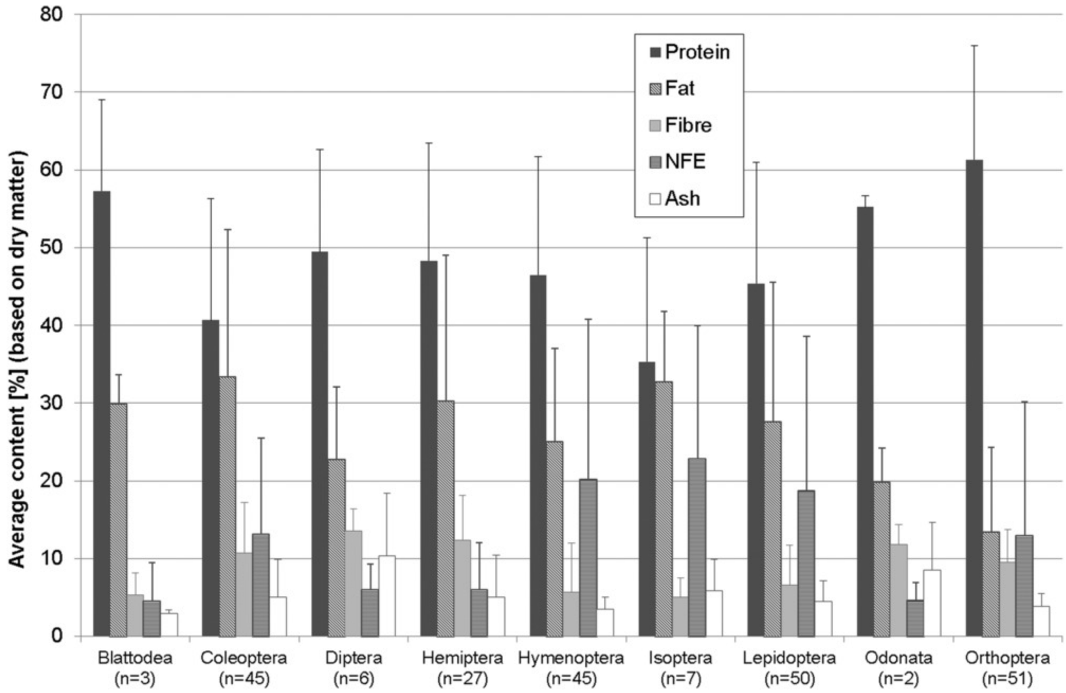

Figure 3 Average nutrient contents [%] (based on dry matter) of edible insects belonging to the same order. n is the number of literature references per order. NFE, nitrogen-free extract. Figure from (Rumpold & Schlüter 2013).

All edible insects meet the amino acid requirements for human adults, with some variation in contents of specific amino acids. Protein digestibility also appears to be high.

Following protein, insects are also rich in fat (see fig 3). The previously mentioned order Orthoptera has the lowest fat content, averaging 13,41% while the highest amount is found in the order Coleoptera (beetles) averaging 33,40% fat. Larvae can in some cases contain very high amounts of fat, such as palm weevil larvae with an average content of 69,78%. The fatty acid composition varied widely between species and within orders. Average fatty acid composition (as percentage of total fatty acids) for seven orders is shown in fig. 4. Generally, the saturated portion of the fat mainly consists of palmitic acid (C16:0) and stearic acid (C18:0). Palmitoleic acid (C16:1n7) and oleic acid (C18:1n9) are the most prevalent monounsaturated fatty acids (MUFA), while the primary polyunsaturated fatty acid (PUFA) varied between linoleic acid (C18:2n6), alpha-linoleic acid (C18:3n3) and arachidonic acid (C20:4n6). Also present were γ-linolenic acid (C18:3n6), dihomo-γ-linolenic acid (C20:3n6) and eicosapentaenoic acid (C20:5n3). One study looking at fatty acid composition in meat found (out of total fat) 4,9 % PUFA in beef (sirloin steak), 5,9 % PUFA in lamb (lamb chops) and 19,9% PUFA in pork loin (Enser et al. 1996). This can be related to the total fat content in muscle that was determined in the same study (g per 100 g muscle) of 3,84 ± 1,3 g in beef, 4,73 ± 1,66 g in lamb and 2,26 ± 0,7 g in pork. Compared to meat, insects thus contain more PUFA both in relative terms (percentage of total fatty acids) as well as in total on a per 100 g basis, except for pork which has a similar total PUFA as some insect orders. A higher intake of PUFA's is generally recommended in national food guidances, e.g. the Swedish national food guidance (Swedish Food Agency 2020b).

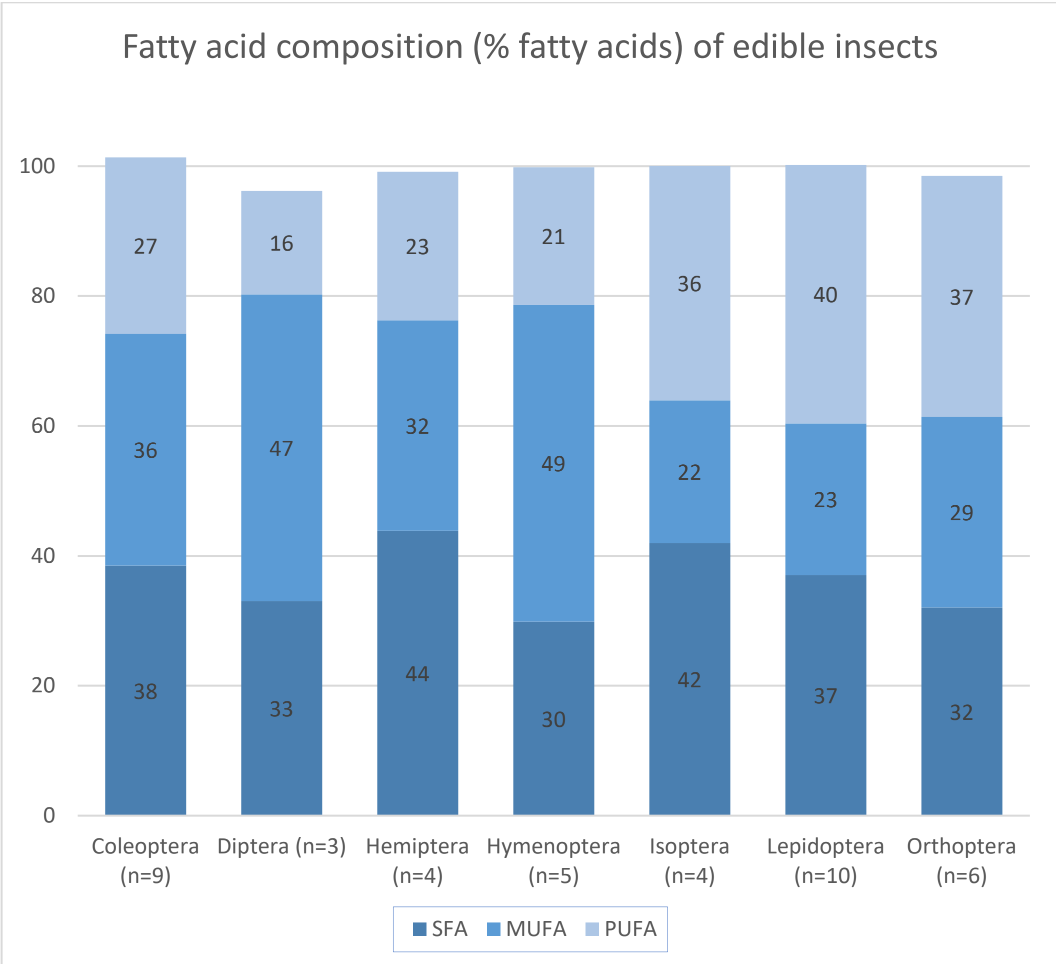

Figure 4 Average content of saturated, monounsaturated, and polyunsaturated fatty acids (as percentage of total fatty acids) in edible insects of seven orders. Because these are sums of averages not all bars sum up to 100 %. (n=x) indicates the number of references for each order. Adapted from (Rumpold & Schlüter 2013)

Owing to the content of chitin, insects contain dietary fibre. Chitin is a polymer of N-acetylglucosamine linked by 1-4 beta glycosidic bond, and is as such essentially indigestible and considered a dietary fibre (some animals including humans possess chitinases, but only to a small degree) (Halloran et al. 2018). Chitin is an integral part of insect exoskeleton, which gives strength and stability to insects. As insects are built differently, chitin contents vary between species and between life stages of the same species. For example, adult beetles, with more exoskeleton, generally contain more chitin than the larvae of the same species. In fig. 3, average fibre contents of edible insect orders is presented, ranging from 5% in Isoptera to 13,56% in Hemiptera (Rumpold & Schlüter 2013). Within the orders, significant differences exist. Black ants *Polyrhachis vicina* can contain as much as 29% fibre while honeybee larvae contain around 1% fibre.

Rumpold & Schlüter also compiled data on vitamin and mineral content, and concluded for minerals that:

> "(…) although a 100 g of edible insects generally lack sufficient amounts of calcium and potassium, edible insects have the potential to provide with specific micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc." Rumpold & Schlüter, 2013

Specific contents vary, with some insects being particularly rich or poor in certain minerals, but in general insects are good sources of minerals for humans. As for vitamins, riboflavin, pantothenic acid and biotin are found in good amounts in most insects. Orthoptera and Coleoptera are generally good sources of folic acid. Vitamin E, vitamin A, vitamin C, thiamin and niacin are generally not found in good amounts in insects. Rumpold & Schlüter (2013) also point out that more data is needed on vitamin content in insects. A recent study on the content of vitamin B12 in mealworms, crickets, cockroach and grasshoppers on whole-body basis, showed a vitamin B12 content of 1,08; 2,88; 13,2 and 0.84 µg/100 g respectively (dry weight) for these insects (Schmidt et al. 2019). These values are lower than contents in meat (Gille & Schmid 2015), however the levels are high enough to possibly contribute to the daily need of 2 µg /day for adult people (Swedish Food Agency 2021). If the insect feed is supplemented with additional calcium, higher amounts of calcium can be found in the insects according to a study on mealworm and house cricket, insinuating that the micronutrient content of insects is malleable (Anderson 2000).

As protein and fat are often present in high amounts in insects, and the protein quality is good, insects could potentially present an interesting source of food in countries that struggle with supplying protein-rich foods to people with diets of low nutritional value. The intrinsic contents of minerals and vitamins accentuate this value. Especially interesting is the possibility to modify the nutritional value of insects, for example the contents of specific minerals, both with the purpose of using insects as human food and as feed.

3.3.2. Safety

In 2015, EFSA released a report on the safety of insects as food, wherein different aspects of food safety in insects were examined. The EFSA argues that as long as currently allowed feeds are used to produce insects, the microbiological safety of these insects is comparable to the microbiological safety of other animals reared on the same feed (EFSA Scientific Committee 2015). Prions, the cause of spongiform encephalopathy, might be present in unprocessed insects if the insects are raised on substrates containing protein of ruminant or human origin (faeces). However, prions will not replicate in insects, meaning that they cannot be seen as amplifiers, only mechanical vectors. Although the statement of microbiological safety assumes that insects would be fed only feed of non-animal origin, the EFSA report also analysed other types of substrates from a theoretical view. One is food that was intended for consumers but discarded, for example due to expired use-by date or manufacturing/packaging defects, which may include meat and fish. Other substrates include slaughterhouse waste (feathers, hides etc); food waste (including animal origin food) from restaurants, catering and households; animal manure; gardening and forest waste and lastly human manure and sewage sludge. The reason for also investigating these types of currently unallowed substrates is, as the authors argue:

> The increased focus on insect rearing is very much based on the potential of insects to convert organic material of low quality into high quality food and feed. Therefore, there is an interest for potential use of types of organic materials as substrate other than those approved by the current legislation. (EFSA Scientific Committee 2015)

The risk analysis compared risks in non-processed insects with risks in unprocessed products from other animals. The biological risk was deemed equal or lower for all feeds except animal and human manure, and sewage sludge, for which the risk was deemed “unknown”. The report suggests that these risks should be evaluated based on each situation, as heat-treatment of the substrates may reduce risk. For prions, the risk was deemed unknown for human manure, and equal or lower for all other substrates if they did not contain material of ruminant origin, in which case the risk was deemed unknown. Essentially, the EFSA report stated that insects are safe when fed currently allowed feeds, and may be safe in other cases too, but these other substrates must each be tested before definite statements on their safety can be made.

Whole insects, usually blanched, frozen or dried, should be labelled with instructions for how to prepare the insects for safety reasons, which EFSA argues is no different from the labelling of safety instructions on raw chicken packages.

To increase consumer acceptance for, and industrial interest in, edible insects, official statements on safety are of high importance. As argued in the book Edible Insects in Sustainable Food Systems (Halloran et al. 2018), consumers look to trusted sources for information about food safety:

> The fact that edible insects are tolerated by authorities in only a few countries in Europe could reinforce the idea that insects may not be edible or safe to eat (Halloran et al. 2018)

Extrapolating from this quote, it could be said that although pioneers and start-up companies may well know that their products are safe, the average consumer might not trust their advertising and rather rely on official statements. Fear of foods being unsafe is one very important factor in deciding what to eat, so if insects can be safe to consume, this is important to convey in official statements and policy. As insect production is not typically recorded in national food production databases, FAO does not include insects (apart from bee & silkworm production) in the FAOSTAT database (FAO 2021a). The fact that the worlds' largest authority on food does not consider insects in their main databases could potentially contribute to the thought that insects are not food. Within the framework of "novel foods", the EFSA released a scientific opinion in January 2021, judging thermally dried yellow mealworm (*Tenebrio molitor*) as a safe food (EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA) et al. 2021). This was the first insect to be approved as safe by the EFSA, which are also as of spring 2021 in the final steps of determining the safety of crickets, locusts and lesser mealworms.

3.3.3. The gourmet bug

When discussing the gastronomic potential for insects, two very different perspectives can be used: traditional use and "novel foods". While insects as food may be a new concept in many European countries, it would be incredibly narrow-minded to focus solely on the "novel foods"-part of insect production. If two billion people are already consuming insects, we can look to their traditional preparation methods for inspiration. For example: in a previously mentioned study on Thai insect consumers by Han et al. (2015), some consumer argued that insects should be fried crisp, as they will become too soft if boiled or steamed. In the same study, Dutch consumers admitted that lack of cooking skills prevented them from consuming insects as they did not know how to prepare them in a satisfying manner. In Thailand, sale of insects has expanded to supermarkets where uncooked, frozen insect products can be bought at high demand and high price relative to other meat types (Yupa Hanboonsong et al. 2013).

Locusts, which are easy to gather in large amounts when they swarm, are consumed in many places across the world. The FAO page Locust Watch describes a number of recipes from places where the locusts swarm (Locusts and Other Migratory Pests Group 2009). A Cambodian recipe suggests stuffing the locusts with peanuts, and then frying them in a wok with oil and salt. In the Philippines, locusts can be cooked "adobo style" in a marinade of soy sauce, vinegar, garlic, bay leaf and black peppercorns, and then fried for crispiness. In Uganda, locusts can be served fried with onion and spiced with curry powder.

In Mexico, grasshoppers called *chapulines* are first killed by boiling them in water spiced with garlic and lime, then toasted in oil and finally served with salt and lime juice (Cohen et al. 2009). In modern restaurants, chapulines are also used in more experimental cooking such as being made into salsas or used as stuffing in stuffed peppers (*chile relleno*).

The novel-food perspective of insect-based food production, which could be seen as the non-traditional use of insects, is strongly oriented towards incorporating whole, ground insects, or insect protein isolates into a compounded product that does not contain visible insects. Examples are the powder based nacho chips, cookie flour mix and protein shakes made by American cricket company Chirps (Chirps Chips 2021). Swedish start-up Tebrito created a taste-neutral protein intended for industrial food applications (Tebrito 2021). Belgian KRIKET produces bars containing cricket powder. Interestingly, the cricket powder used by KRIKET is made from crickets raised on “leftovers from the food industry”, which is used in KRIKETS advertising (Kriket 2021). German Bug Foundation produces a ready-to-cook hamburger containing 1/3 ground lesser mealworm (*Alphitobius diaperinus*) sold in restaurants and supermarkets (Bugfoundation 2021). Netherlands Nimavert makes , among other things, ravioli and croquettes with mealworm powder and tapenade with cricket powder (Nimavert 2021). Clearly, the European start-up insect food industry mainly orients itself towards invisibly incorporating insects in all sorts of products, usually replacing either flour, protein powders from other sources or meat in products like ravioli. One study tested mealworm as partial flour replacer in tortillas (Aguilar-Miranda et al. 2002). Tortillas were prepared with 6,67% of maize flour replaced with mealworm powder, and analyzed by triangle test with 18 trained judges. The triangle test indicated significant differences between the larvae-maize tortilla and the control, however when asked about their opinions, judges showed acceptance for the larvae-maize tortilla, with higher rates for taste, mouthfeel, and functionality (for taco-rolling) compared to the control tortilla. This study shows the potential of insect ingredients to improve properties of foods, and not just participate in foods as a hidden ingredient.

Apart from the powder-oriented products, several companies also produce whole-insect products. Finnish Griidy makes whole toasted crickets; flavour-neutral or flavoured with sea salt, garlic or Mexican spice mix, which are intended as snacks or as toppings on pasta, salads or tacos (Griidy 2021). Previously mentioned Nimavert also produces roasted and flavoured crickets and mealworms.

3.4. Insects as feed for fish

The interest for using insects as feed for fish has increased in recent years, owing to the public dislike for fish meal-production and its consequences on global fish stock. Currently, not just any insect can be used as feed for animals. Within the EU, processed protein derived from insects can be produced to use as feed from black soldier fly, common housefly, yellow mealworm, lesser mealworm, house cricket, banded cricket and field cricket (European Parliament & European Commission 2011). As pointed out by Turek et al. (2020), insects are a major part of salmonid diets during growth and in some cases throughout the lifespan of the fish. Thus, although industrially farmed insects are a relatively new concept in fish food formulation, it does still make biological sense (Turek et al. 2020). Much research in recent years has been focused on determining the various effects on fish of replacing fish meal in feed with insects. Different perspectives on insects as fish feed will be examined in this section. Some generalizations will be made but as the research designs vary massively, not all studies are comparable.

3.4.1. Impact on growth parameters

Most investigated studies show a positive or neutral effect on growth parameters of fish. To simplify, these will be described according to investigated insect species.

Results for black soldier fly larvae (BSFL) range from a maximum recommended fishmeal substitution of 25% to a full 100% replacement of fish meal, however these results depend on the composition of the fish feed and fish species. With all diets containing fish oil, Lock et al. (2015) found 100% substitution of fish meal with BSFL to give a reduced feed intake and improved feed conversion ratio in salmon, resulting in equal net growth as the control. With fish-offal enriched BSFL replacing 50% of fish meal, growth in rainbow trout was similar to the control while un-enriched BSFL gave a significantly decreased growth performance (Sealey et al. 2011). When defatted BSFL replaced fish meal in diets of *Cyprinus carpio*, growth performance and nutrient utilization was not different between control, 25, 50, 75 and 100% fish meal replacement (Li et al. 2017). However, intestinal damage above 75% caused the authors to recommend no higher fish meal substitution than that. For Siberian sturgeon (*Acipenser baerii*), substitution was recommended no higher than 25% (Caimi et al. 2020) while European seabass (*Dicentrarchus labrax*) grew well on the highest tested 45% substitution (Magalhães et al. 2017). For rainbow trout, one of the more commonly studied fishes, recommendations for BSFL inclusion vary between 25 and 50% fish meal substitution or 25% to 40% inclusion (mainly but not only replacing fish meal)(St-Hilaire et al. 2007; Renna et al. 2017; Dumas et al. 2018; Józefiak et al. 2019a; Secci et al. 2019; Terova et al. 2019).

Mealworm (*Tenebrio molitor*) is apart from BSFL a popular candidate for fish feed, with many studies investigating the effects. Mealworm supplemented feeds often show an improved growth performance compared to control. Rainbow trout had improved growth performance at 20 % inclusion (Józefiak et al. 2019a) and no difference in growth at 50% inclusion (Gasco et al. 2015). Improved growth rate, feed conversion rate and final weight was found at 100% substitution (Rema et al. 2019) while improved feed conversion rate and protein efficiency was found in another study at 30% substitution (Belforti et al. 2015) Seemingly, mealworm could well be used as fish meal substitution for rainbow trout.

No effect on growth was found at 15% mealworm inclusion for Siberian Sturgeon (Józefiak et al. 2019b), at 50% fish meal substitution for Yellow catfish (*Pylodictis olivaris*) (Su et al. 2017) or at 30% inclusion (replacing fish meal) for Mandarin fish (*Siniperca scherzeri*) (Sankian et al. 2018). Given the desire to reduce fish meal use, an unaffected growth performance means that mealworms may still have use as feed for these fish.

Gilthead sea bream (*Sparus aurata*) had improved growth performance at 35% fish meal substitution but worsened performance at 71% substitution (Piccolo et al. 2017). Meagre (*Agryrosomus regius*) had decreased performance already at 25% substitution and linearly decreasing growth parameters with increasing fish meal substitution (Coutinho et al. 2021), while European seabass had acceptable performance at 35% substitution but worsened above that (Gasco et al. 2016). These results indicate that mealworms may not be suitable for all fish, and that research is necessary to determine the adequate levels of inclusion for each fish species.

It should also be mentioned that some other insects have been studied with varying results. A high content of chitin (45%) was attributed to locusts poor performance as feed for European seabass (Basto et al. 2020). Banded crickets caused intestinal damage and reduced growth in rainbow trout (Józefiak et al. 2019a) while two-spotted crickets (*Gryllus bimaculatus*) substituting 100% of fish meal gave significantly higher weight gain in rainbow trout (Taufek et al. 2016). Jamaican field cricket (*Gryllus assimilis*) had significantly lower digestibility in Nile tilapia (Fontes et al. 2019). House crickets (*Acheta domestica*) gave similar growth performance in rainbow trout as control when replacing 25% of energy in standard feed, as did a mix of 50/50 house crickets and superworm (*Zophobas moria*) (Turek et al. 2020). When house crickets and zophobas replaced 25% of fish meal in the diet of Perch (*Perca fluvatilis*), however, growth performance was significantly impaired (Tilami et al. 2020). Thus, positive results for one cricket species might not be possible to generalize to other cricket species.

3.4.2. Fish health when fed insects

Studies examining fish health when insects are used in the feed usually focus on immune system function, and some studies have examined the effects on gut microbiota.

Immune system function is often determined by measuring serum levels of lysozyme, pro- or anti-inflammatory gene expression levels and disease resistance when exposed to pathogens. Positive effects have been found from black soldier fly on reduced inflammation and enhanced immunity (Kumar et al. 2021; Xu et al. 2021). Mealworm gave improved immune response and increased serum lysozyme levels (Su et al. 2017; Henry et al. 2018b; a; Sankian et al. 2018; Ido et al. 2019), increased antioxidant intestinal enzymes and increased antibacterial serum activity (Henry et al. 2018a) reduced inflammation (Henry et al. 2018b) and improved survival of red seabream exposed to pathogens (Ido et al. 2019) One study also showed a positive effect from mealworm on pathogen resistance of Vannamei shrimp (Motte et al. 2019), while Superworm (*Zophobas morio*) had a positive effect on Nile tilapia serum lysozyme levels (Alves et al. 2021). Some argue that insect exoskeleton may have physiological similarities to fish parasites, which although not harmful in themselves may stimulate the immune system (Henry et al. 2018a).

Generally, insects seem to have a beneficial effect on fish gut microbiota, as evidenced by an increase in richness and diversity and increased amount of beneficial bacteria such as lactic acid bacteria in fish fed insects (Huyben et al. 2019; Józefiak et al. 2019b; Terova et al. 2019). This effect is usually attributed to the contents of chitin, the exoskeleton component that can be fermented by gut microbiota. Improved gut health may also be an explanation for positive general health effects observed in these studies.

3.4.3. Nutritional value of fish fed insects

Many studies suggest that the fatty acid composition of the fish is modified by and often reflects the fatty acid composition of the diet. When fish are fed saturated fatty acid-rich black soldier fly larvae, saturated fatty acids increase in relative amounts mirroring the diet (Borgogno et al. 2016; Secci et al. 2019; Bruni et al. 2020). Inclusion of mealworm meal seems to increase contents of saturated fatty acids, C18:1 and C18:2(n-6) while decreasing other polyunsaturated fatty acids (Belforti et al. 2015; Gasco et al. 2016; Sankian et al. 2018).

The content of EPA and DHA in fish are affected by the contents of these important fatty acids in the diet, as reflected by many studies showing a decrease in these and other omega-3 fatty acids in fish fed insects (St-Hilaire et al. 2007; Belforti et al. 2015; Gasco et al. 2016; Renna et al. 2017; Turek et al. 2020). Pointing in the opposite direction, one study examined the genetic expression of desaturase and elongase enzymes (involved in synthesizing long-chain-PUFA) and found an upregulation of gene activity in rainbow trout fed decreasing amounts of EPA and DHA (as caused by a reduction in fish meal content) (Bruni et al. 2020). The contents of these fatty acids in examined fish did not differ significantly even when half of the fish meal (originally 420 g/kg) was replaced with full-fat black soldier fly prepupae meal, and fish oil was reduced from 70 g/kg to 28 g/kg. This indicates that although EPA and DHA are important to the fish, they may not be fully dependent on the contents of these fatty acids in their diet. Another study examining the effects of separating EPA and DHA in feed found that most EPA fed to salmons was metabolized for energy, while DHA was incorporated effectively into tissues (Emery et al. 2016). The authors thus argue that salmons have a higher need for DHA than EPA. Perhaps this could explain the lack of difference found by Bruni et al. (2020), as these fish were still fed some, if less, EPA and DHA. It is worth considering, that as full-fat insect meals are often rich in fat, the amount of fish oil was reduced in most of these studies to reach a fat content in test diets like the control, thereby reducing EPA and DHA contents further. Enriching insects with EPA and DHA by feeding them marine substrates, as explored in section 3.1.1. "Marine substrates", could be one way to ensure the supply of EPA and DHA for fish eating these insects, however research in this area is still scarce. One study found a higher content of EPA and DHA in fish fed enriched black soldier fly larvae (Sealey et al. 2011). However interpretation of these results is made difficult by the fact that all diets used in this study contained fish oil. The fatty acid composition may also differ slightly from feed to fish, as not all fatty acids are used equally as sources of energy. A higher amount of C12:0 in BSF larvae meal was not reflected in the fatty acid composition of salmon even at 100% fish meal substitution (although all diets contained fish oil). The authors suggested that this may have been because the easily digested C12:0 was preferentially metabolized for energy (Lock et al. 2015).

Protein content and amino acid composition does not seem to be affected by feed inclusion of various insects (Kroeckel et al. 2012; Khosravi et al. 2018; Belghit et al. 2019; Rema et al. 2019). This might be attributed to the high protein contents and good amino acid composition of many insects as discussed in a 2019 review (Nogales-Mérida et al. 2019).

3.4.4. Sensory experience of fish fed insects

How do fish that were fed an insect-based feed taste? It is natural to assume that the feed of the fish can have an impact on its perceived quality, and this has been examined in a few studies. When rainbow trout was fed black soldier fly larvae, a panel of ten trained assessors experienced a more dominant metallic taste in fish fed diets with 25% and 50% fish meal substitution. However, this was described as different, not inferior (Borgogno et al. 2016). At 50% fish meal substitution the fish was perceived as juicier and more tender, which was attributed to water content. No off-flavours or other sensory defects were detected.

In a blind comparison test, 30 untrained panellists could not tell the difference between standard feed-fed rainbow trout and those raised with a 25 or 50% substitution of fish meal with omega-3-enriched BSFL (Sealey et al. 2011).

Eleven trained assessors found no significant difference in odour, flavour or texture in Atlantic salmon (*Salmo salar*) given feed with 25, 50 or 100% substitution (all feeds containing fish oil) (Lock et al. 2015).

Regarding technical quality, water holding capacity, pH or shear stress, no significant impact was found in several studies; inclusion of 50% BSF pre-pupae in rainbow trout feed (Bruni et al. 2020), 25% fish meal substitution with defatted BSFL in rainbow trout feed (Secci et al. 2019) or 100% fish meal substitution with BSFL in Atlantic salmon feed (Belghit et al. 2019).

When all feed was replaced with 50/50 House cricket and superworm in rainbow trout diet, 10 trained assessors scored a significantly lower acceptability for aroma and taste with a strong aftertaste (Turek et al. 2020). However, in the same study, 25% of energy in standard feed could be replaced with housecricket, superworms or a mix of both without causing significant differences from the control.

As few studies have yet been performed, more research is needed to generalize effects on the sensory quality of fish fed insects.

4. Conclusions

4.1. Food waste utilization

Insects seem able to use a wide variety of substrates as feed for survival and growth. The nutritional value of the insect can be affected by what feed they are supplied. Most clearly affected are the fat composition, the mineral content and the vitamin content. Fat composition of the insect feed substrate is often reflected in, or at the very least impacts, the fatty acid composition of the insect. Mineral- or vitamin-enriched substrates can give a higher final content of the enriched nutrients in the insect.

Insects present a unique opportunity for not only management of food waste, but also resourceful and environmentally clever use of it. The question on whether food waste can be used to raise insects in a sustainable way can thus be answered with a yes, probably. Cycling the captured nutrients found in food waste back into the food systems through insects could be a good way of increasing efficiency in food production systems. Although research in this area is booming, more in-depth, practical studies with real-life food waste sources (which follow current feed regulations) would greatly benefit the development within the sector and increase its real-life applicability. When deciding which food waste sources to use, analysis from an economic viewpoint will probably also be necessary to give enough profitability for engaged companies. Furthermore, exploration of not currently allowed feed sources such as additional animal source substrates could give new perspectives on safety and resource efficiency. Maybe, animal source substrates could be used to rear insects intended to be used for biofuel production, while vegetable substrates could be used to rear insect for food and feed use.

As the world demands more protein, both from animal and plant sources, sustainable food production becomes critical. Markets for plant-based meat substitutes are growing, as consumers seek sustainable alternatives. The ability of insects to use substrates of lower quality to produce high-protein, nutritious food material makes them an attractive alternative to both plant and animal foods, a sustainable third option.

4.2. Insects as food

A high protein content and a good amino acid composition for human nutrition, as well as mineral and vitamin contents at levels that can satisfy human needs, gives insects a good composed nutritional value for humans. Some insect species, especially in the larval stage, tend to have high fat contents. This can present advantages of high energy contents, relevant for undernourished people. However, the common high contents of saturated fats could be a disadvantage when viewing health effects of insect consumption. Still, insects can be said to have a good nutritional value for humans.

Neophobia and disgust may prevent the expansion of the insects-as-food market in areas of the world not traditionally consuming insects. Behavioural research indicates that disgust and neophobia may be preventable, as cultural norms and habits strongly influence preferred eating habits (Dovey et al. 2008). Efforts to introduce insects as food in school and childcare settings such as the introduction to cricket farming in Thailand (Yupa Hanboonsong et al. 2013) are interesting, especially as this has potential to decrease the risk of neophobia and disgust towards insects. Schools could have potential as places to introduce insects to European children. Although many adults in Europe probably would not even consider serving insects to their children, schools could maybe serve insect-based foods like burgers; where the insects are hidden yet not "secret" as neophobia can only be prevented if the children are aware that they are eating insects, and still accept it. Still, it can be argued that constantly placing insects as food within the "novel foods" category is disrespectful towards all the many cultures where insects are traditionally consumed. Rather than exotifying insects, interested parties can benefit from learning from those with traditional knowledge about insect preparation. Although insect protein powders and isolated components carry interesting promises for industrial food development, the wheel might not need to be reinvented when it comes to finding good use of insects as a future source of food.

In conclusion, if neophobia and disgust can be managed and decreased where it occurs, the good nutritional value of insects makes it an interesting future source of food.

4.3. Insects as feed for fish

As insect production systems are developed while insects as food may still be controversial in some parts of the world, the herein presented research suggests that there is great potential for using insects as fish feed. Both black soldier fly larvae and mealworms can constitute a large portion of fish feed when formulated with care. Research on the sensory quality of insect-fed fish is still in its infancy and further exploration of this area is necessary to ensure a meaningful production without unexpected quality defects, but initial results seem promising. De-fattening the insect meals may sometimes be advisable, and composition of the feed apart from the insect component should be performed with research on the specific insect and fish species intended in mind. As for the nutritional value of fish raised with insects as significant feed component, the general amino acid, mineral and vitamin composition does not have to be negatively affected. Regarding fatty acid composition, each researcher, company, or individual will have to consider their own priorities. Marine omega-3 fatty acids (eicosapentaenoic acid, EPA, and docosahexaenoic acid, DHA) are generally seen as valuable for humans, but research and opinions about this is contradictory. Although it can always be argued that "more research is better", in the case of omega-3, a bit of pragmatism may be of value. Epidemiological research on nutrition is always fraught with confounders and covariance, with everything from country of residence to socioeconomic status playing into an incredibly complex mesh of positive and negative health effects. One sole component of a human diet can rarely (although not never) be isolated and explained as relating to health outcomes, and it can be argued that the same applies to the marine omega-3 fatty acids. Regardless, fish is generally a good source of food, rich in nutritious components, a good source of protein, and this seems to apply to fish raised on insects as well. Thus, omega-3 controversy and all, it can be concluded, based on the research presented in this report, that insects hold great promise as sustainable fish feed. As with insects as food for humans, the potential for an environmentally friendly production increases with creativity in sourcing feed substrates for the insects.

In conclusion, insects present a very promising future source of feed for fish.

4.4. Future research

Future research as suggested by this report may be focused on further testing of different substrates including food waste as feed for insects, analysis of climate impact of insect production and effect on sensory quality of fish fed insect.

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Appendix 1

Popular scientific summary

The worlds population is estimated to grow, which means that more food of good quality is needed. Also, many people want to eat more foods rich in protein such as meat, fish, or vegetarian alternatives. However, the production of food is one of the more important things that contribute to global warming and climate change. To make matters worse, a lot of food that humans could eat is currently either wasted or given as feed to animals. This report investigates whether food waste could be used as food for insects. The reason for this, is that insects are good at concentrating nutrients from substrates of low nutritional value, they can eat many different things, and they contain high amounts of protein. Two billion people in the world consume insects regularly, so although the idea of eating insects seems weird to some people in for example Europe, it is not a new idea in any way. Food neophobia towards insects, which some people experience, is the fear of eating unknown foods. Because many people do not want to eat insects, this report also looks at the potential of using insects as feed for fish. The reason why fish is investigated is because of the current problematic situation where farmed fish are raised on feeds containing wild caught fish, this is not seen as very sustainable especially because often these wild caught fish could be eaten by humans.

The results of this report show that insects can eat many different types of food waste, but there are some things to consider. One is that the feed must be allowed by current legislation. It should also be safe, that is, not transfer disease or contain substances that are toxic or growth-hindering for the insects. Insects can eat, survive, and grow on many different feeds, but there needs to be enough nutrients in the feed for them to survive.

Insects are generally rich in protein and fat, contain good amounts of several important minerals and vitamins and a kind of dietary fibre, chitin, found in their exoskeleton. According to the European Food Safety Authority, insects are safe to eat if the feed they were raised on is safe. In many countries in the world, there is traditional knowledge on how to cook insects. Also, new companies are producing innovative products like protein powders based on insects.

When fish meal is replaced by insects, many fish grow equally well or better than when eating a standard feed. The health of the fish improves in several ways, increasing their resistance to disease. Yet, not all insects are good as feed for all kinds of fish and more research is needed to determine the best combinations. It seems that the taste of fish that were fed feed that contained insects can have an acceptable taste.

In conclusion, insects are a promising source of food and feed for the future, especially if systems can be designed in which the insects are raised on food that currently go to waste.